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STRUCTURAL STYLE OF THE SOUTHERN CANADIAN CORDILLERA

GUIDEBOOK

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STRUCTURAL STYLE OF THE SOUTHERN CANADIAN CORDILLERA

J. O. WHEELER, R. B. CAMPBELL, J. E. REESOR
Geological Survey of Canada

E. W. MOUNTJOY
McGill University

Guidebook Editor
D. J. GLASS
Canadian Export Gas & Oil Ltd.,
Calgary

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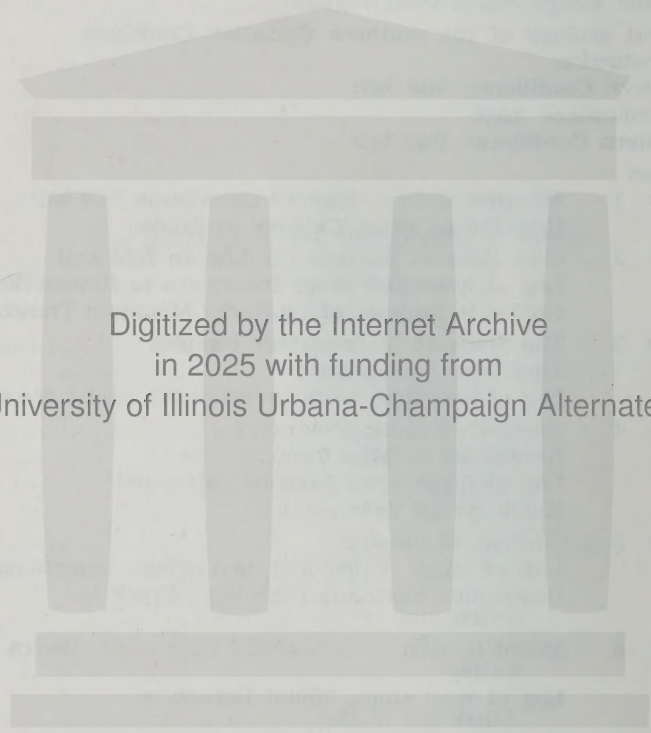

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SUMMARY OF THE TECTONIC HISTORY OF THE SOUTHERN CANADIAN CORDILLERA

INTRODUCTION

Much of the Eastern Fold Belt (Fig. 4) was the site of a miogeocline-platform depositional regime along the western margin of the North American craton from Helikian (Middle Proterozoic) to Late Jurassic time — a period of more than 1,300 million years. It was succeeded by a clastic wedge regime from Latest Jurassic to Paleocene time — a period of about 100 million years. The miogeocline-platform (Fig. 4) in gross aspect comprises several overlapping lenses of sedimentary packets of different ages separated from one another by erosion surfaces. This has resulted from intermittent shifts in the main locus of sedimentation along the wedge and has produced a relatively uniform total thickness (circa 45,000 feet, 13,700 m) from one locality to another. For example, where the Paleozoic is thin, near the 49th parallel, the Purcell is thick; 125 miles (200 km) to the northwest, where the Paleozoic and

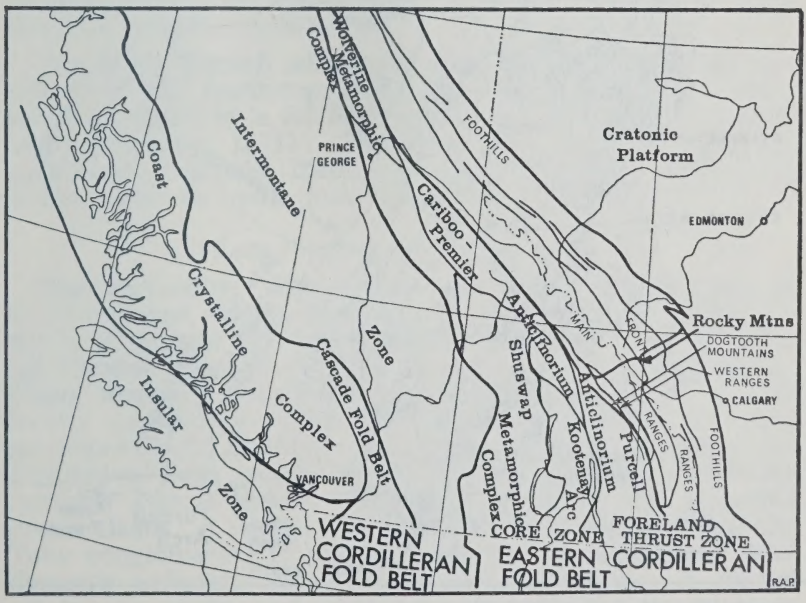


Fig. 4. Major structural belts of the southern Canadian Cordillera (Wheeler, 1970).

Windermere are thick, the Purcell must be thinner in order to be accommodated above the westward projection of the basement surface.

In the more westerly part of the southern Canadian Cordillera a more varied depositional regime, featured by extensive and repeated volcanism, probably partly in an island arc environment, with rapid changes in the distribution, thickness, and character of the sediments, reflects repeated deformation and uplift from Devonian until the late Cenozoic — a period of about 350 million years (Fig. 6). This varied regime interdigitated with and overlapped the western part of the miogeocline.

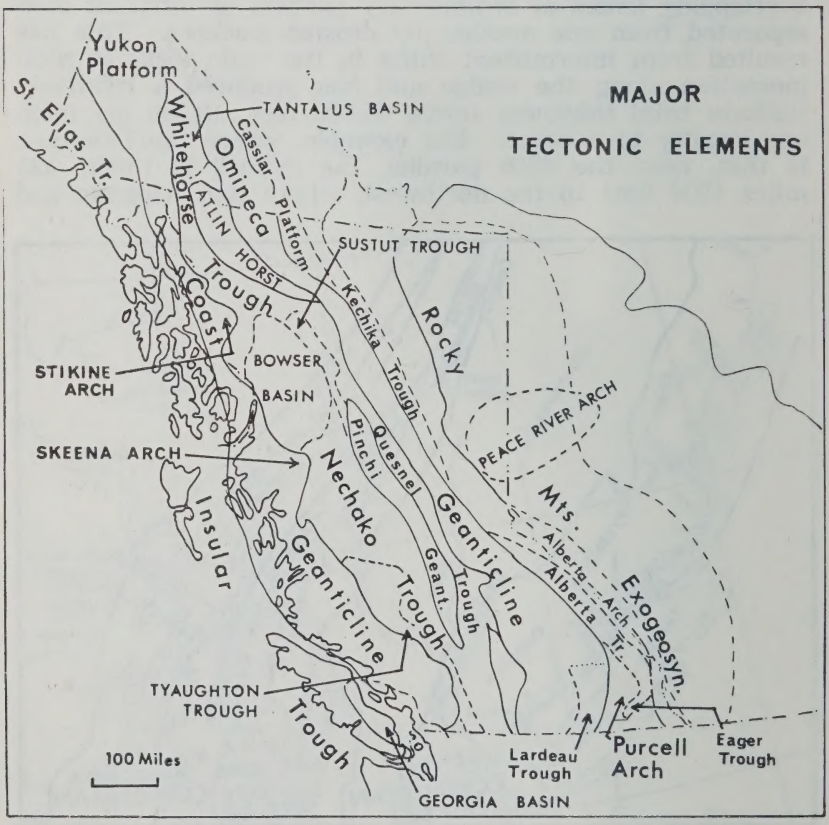


Fig. 5. Major tectonic elements of the southern Canadian Cordillera (Wheeler, 1970).

Eastern Miogeocline-Platform Regime

Middle Proterozoic-Purcell

The depositional regime of the Cordilleran orogen began between 1320 (oldest K-Ar dates on muscovite in the lower Purcell) and 1800 million years ago (approximate age of metamorphism of basement beneath the Purcell equivalent to the south). Fine siliceous clastics and subordinate carbonates of the Purcell accumulated in a westward prograding miogeoclinal trough. The preserved rocks thicken westward from 0 to 35,000 feet (10,700 m).

The lower Purcell comprises shallow-water sediments in its eastern facies in the Rocky Mountains and part are deeper water, northward transported turbidites in the west. The upper Purcell sediments, succeeding the Purcell basic lavas that were extruded about 1,100 million years ago, are shallow water sediments including quartz sandstone, mud-cracked shale, carbonate, and stromatolitic dolomite. The sediments were derived from a large drainage basin of low relief extending far into the interior of the craton. They accumulated in one or more deltas from which slumps presumably generated turbidity currents that transported sediments in a northerly direction.

The lower Purcell sediments were intruded by basic sills, deformed into north-trending folds, and intruded by a granite stock dated by a Rb-Sr isochron at 1260±50 m.y. (Ryan and Blenkinsop, 1971). The outer part of the miogeocline underwent regional metamorphism, locally to sillimanite grade, prior to uplift more than 750 m.y. ago.

Late Proterozoic-Windermere

The succeeding Windermere assemblage accumulated in a miogeocline whose source area and locus of deposition south of latitude 51° was displaced westward from that during Purcell time. The lower two-thirds or so of the assemblage, several thousand feet thick, comprises poorly sorted, locally graded, predominantly quartzo-feldspathic grit and sandstone with shale interbeds. At or near the base, the distinctive Toby conglomerate or conglomeratic mudstone contains Purcell debris and locally volcanic and granitoid gneiss clasts. A recent study (Aalto, 1971) suggests that the Toby conglomerate is a tillite and that the associated Windermere sediments are of glaciomarine origin. A glacial origin may apply to the Toby conglomerate but the evidence is not convincing for the great bulk of the Windermere as-

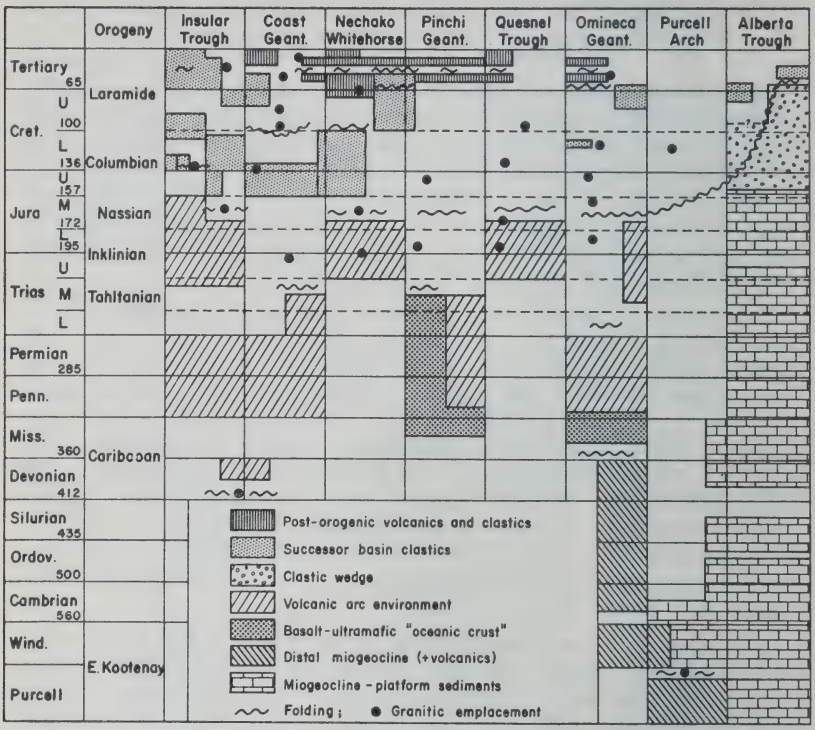


Fig. 6. Tectonic chart of the southern Canadian Cordillera (modified after Wheeler, 1970).

semblage which could equally well have been derived by rapid deposition adjacent to a high relief terrane of crystalline rocks and, locally, of Purcell strata (e.g. south of 51°). Basic volcanic rocks overlie the Toby conglomerate in its westernmost exposures at the International Boundary. The upper part of the Windermere assemblage in the northern Selkirk and Cariboo Mountains is composed largely of pelitic rocks, locally with distinctive maroon and green colours, with carbonate units near the top, which serve as useful stratigraphic markers. In the Purcell Mountains, however, the upper part of the assemblage contains alternating successions of carbonate, shale, quartzite, and grit.

The Broadview Formation, formerly considered to be conformable on the lower Paleozoic rocks in the Kootenay Arc (Fyles and Eastwood, 1962), is considered by Wheeler (in

press) to be an allochthonous sheet derived from a westerly, volcanic bearing facies of the Windermere system. The Broadview Formation has many characteristics of typical Windermere lithology including diagnostic blue quartz and it contains basic lavas which, though rare in the Windermere, are known to the south. On a large scale the basal contact of the Broadview truncates the underlying Paleozoic formations.

Early Paleozoic

During Late Proterozoic and Early Cambrian the westward prograding miogeocline (Windermere assemblage) was overlapped by a blanket of commonly cross-bedded quartz sand, now orthoquartzite, probably derived from the eroded and reworked eastern part of the Windermere and from a topographically subdued source on the craton. In the Rocky Mountains the quartzite lies unconformably, though rarely with angular relationships, above the older rocks, whereas in the northern Selkirk and Cariboo Mountains the contact is conformable and deposition was apparently continuous. The blanket is formed of a series of coalescing sand lenses with intervening shale lentils. It thickens westward from a few feet in the subsurface east of the Rocky Mountains to about 8,000 feet (2400 m) about 25 miles (40 km) west of the Rocky Mountain Trench near latitude 51°. At the same latitude still farther west the quartzite thins and intertongues with argillaceous sediments in the Eastern Core Zone. In the northern Selkirks it is assocated with basic flows and minor tuff. The upper part of the quartzite contains increasing amounts of pelite and gradually passes upward into a predominantly shale unit yielding trilobites in parts of the Rocky Mountains. A succeeding widespread shallow-water carbonate unit (Badshot-Mural) mainly of limestone with oolites and pellet beds, locally contains archeocyathids. The carbonate attains a thickness of several hundred to 1,000 feet (305 m) over large areas but far to the west it locally thickens to over 2,000 feet (610 m), then thins abruptly. The quartzite and carbonate represent the most westerly Phanerozoic remnants of the continental terrace wedge.

From Middle Cambrian through the remainder of early Palezoic time the continental terrace wedge subsided. Carbonate deposition on the platform and on the inner parts of the miogeocline terminated in an abrupt bank, now exposed west of the Alberta-British Columbia boundary, beyond which argillaceous and limey clastics (Chancellor-McKay-

Glenogle) accumulated to a total apparent thickness of 16,000 feet (4,900 m). Some of the thickness may be attributed to tectonic thickening.

Farther west, pelitic sediments formed relatively thin carbonaceous and locally pyritic condensed sections; an environment in which graptolites were preserved. From time to time quartz sand, perhaps derived from orthoquartzite exposed in the Peace River and Alberta Arches, was swept along the coast by long-shore currents. Basic flows, commonly pillowed, and some pyroclastics(Jowett, Index in part) were deposited with the deeper water sediments in the western part of the miogeocline.

During the early Paleozoic the Purcell Arch near latitude 50°30′ was intermittently emergent. During periods of submergence the arch received thin sequences of shallow water carbonate, quartz sand, and pelite interrupted by disconformities.

Late Paleozoic to Early Mesozoic

The late Paleozoic was marked by a considerable change in regime throughout most of the Eastern Fold Belt. The region southeast of Pine Pass (Lat. 55°20′, Long. 122°30′) remained a relatively stable yet gently fluctuating shallow water platform upon which accumulated thin (incomplete) sequences of carbonate, quartz sand, phosphate, and chert broken by several disconformities. Northwest of Pine Pass the region received a great flood of shale from a source not yet identified but perhaps derived in part from a clastic wedge associated with the Devono-Mississippian orogeny in Northern Yukon and in part from uplift in the Eastern Core Zone related to the Cariboo orogeny.

The Cariboo orogeny in the southeastern Cordillera is manifested by overthrusting in the Kootenay Arc of a western volcanic-bearing facies of the Windermere (the Broadview Formation) over the deep-water pelites of the outer part of the miogeocline. About 30 miles (50 km) southeast of Revelstoke, variously oriented boulders of foliated Broadview rocks in Upper Mississippian conglomerate and a recently discovered angular unconformity between the Mississippian and Broadview units (P. B. Read, 1971, pers. com.) indicate that the emplacement and accompanying deformation of the Broadview took place prior to the Late Mississippian. Such *décollement* thrusting of the Cariboo orogeny is consistent with the style of deformation of the Late Devonian - Early Mississippian Antler orogeny in the U.S. Cordil-

lera. A further expression of the orogeny in the Cassiar Mountains, 800 miles (1,290 km) to the northwest, may be the anomalous emplacement onto miogeoclinal rocks of a thick basic volcanic sequence of Devono-Mississippian age which was subsequently deformed and overlain unconformably by Upper Mississippian strata. The concept of tectonic emplacement of the volcanic sequence needs to be confirmed.

Triassic deposits of the platform regime in the Rockies disconformably overlie the Permian, the hiatus increasing eastward. Siltstone, shale, and sandstone, derived from the craton to the east and north, accumulated up to thicknesses of 2,800 feet (850 m) in a marginal basin bordering the craton. Early and Middle Jurassic clastics, similar to the Triassic and probably also derived from the craton, were laid down with local disconformity on the Triassic to form thin sequences interrupted by disconformities. Upper Jurassic strata were deposited as the sea retreated eastward over the craton and platform sediments away from the emerging orogenic belt in the west (Columbian orogeny). From Upper Jurassic to early Tertiary sediments of the clastic wedge poured in from the rising land to the west.

Island Arc-Inter-Arc Basin and/or Oceanic Basin Regime

Late Paleozoic

The upper Paleozoic rocks west of the Eastern Fold Belt fall into three belts (Monger, 1972). The eastern belt lies along the western flank of the Omineca Geanticline (Fig. 5), the central belt within the Intermontane Zone, and the western area along the Coast Geanticline, Cascade Mountains, and Insular Zone. The eastern and western belts, particularly the latter, appear to have been relatively mobile volcanic arcs. The western belt, which is displayed in the southern Cordillera in the western Cascade Mountains, contains mixed volcanics (andesite, basalt, and rhyolite with abundant pyroclastics); clastics, partly terrigenous and partly volcanogenic, and locally containing fossil plants; and impure carbonates locally with shelly fauna, up to 2,000 feet (610 m) in thickness. The sequences are broken by unconformities. The eastern belt is not as well known as the western but has similar mixed volcanics, clastics, and impure carbonates.

Late Paleozoic rocks of the central belt, by contrast, are mainly basalts (generally tholeiitic), pillow lava, gabbro, and ultramafics interpreted as oceanic crust formed in an oceanic

or inter-arc basin. The sediments are mainly ribbon chert, commonly with radiolaria, occasionally the apparently uninterrupted sequences (Mississippian to Permian in the Atlin Horst in northern British Columbia) up to 6,000 feet (1830 m) thick of pure, shallow-water carbonates, and rare clastic sediments and melanges. Blue schist facies metamorphism is restricted principally to the eastern part of this belt and to the zone flanking the core of the Cascade segment.

Early Mesozoic

Nowhere in the eugeosynclinal part of the Canadian Cordillera have Lower Triassic strata been recognized although strata of this age occur in Washington State just south of the International Boundary. Middle Triassic strata where identified have the same lithology as the Permo-Carboniferous.

The main tectonic elements (Fig. 5) became established in early Late Triassic time following the Tahltanian orogeny — an interval of deformation and of low-to-medium-grade regional metamorphism recognized principally in northern British Columbia but also displayed near Greenwood, just north of the 49th parallel. The remainder of the early Mesozoic (Late Triassic to Middle Jurassic) history of the eugeosynclinal part of the Cordillera was characterized by extrusion of abundant andesitic and basaltic volcanics, some of which are alkaline. The volcanics were probably extruded in part from centres along island arcs, and in part as submarine flows in adjacent troughs and basins, which also received from the arcs thick accumulations of volcanogenic and terrigenous sediments.

The tectonic relief is recognized on the basis of gross changes in facies of volcanics and sediments — primarily from southern Yukon and northern British Columbia — where there is less masking cover of Tertiary volcanics than elsewhere. The geanticlines in the north were probably the sites of island arcs that were only partly volcanic. The flanks of the geanticlines are outlined by sequences of variable thickness, interrupted by unconformities, and composed of coarse clastic sediments with shelly fauna and fossil plants. The sediments are commonly conglomeratic and locally of subaerial red-bed facies whereas the volcanics contain coarse breccia and bombs. The adjacent trough deposits appear to be thicker, more or less continuous sequences of poorly fossiliferous fine-grained marine clastics with a significant pro-

portion of turbidite beds as well as aphanitic flows and tuffs.

In Late Triassic, volcanism in the southern Cordillera took place mainly in the Quesnel and Insular Troughs (Fig. 5). In the former, volcanics were extruded in two cycles; Karnian basaltic-andesite plagioclase porphyry and Norian basaltic augite porphyry. Findlay (1969) has noted the restriction to Triassic volcanics of the Quesnel Trough of two 200 m.y. old zoned basic and ultrabasic bodies. These appear to have been derived from alkalic basaltic magma and Findlay suggests that the Triassic volcanics were derived from the same parent magma. Several 200 m.y. old quartz diorite and granodiorite plutons, which contain important porphyry copper and molybdenum deposits, are also closely associated with regions of Triassic volcanism. These may be subvolcanic plutons within a volcanic arc. Apparently these plutons reached their final level of emplacement after gentle warping and normal faulting had affected the volcanic pile. Subsequent rapid erosion exposed the plutonic rocks and shed debris from them in Lower and Middle Jurassic time. Although meagre data suggests a general increase toward the east in K_2O/SiO_2 ratios of lower Mesozoic volcanics (Souther, 1972) much more must be learned about the facies and chemistry of these rocks before speculations can be considered that one or more east-dipping subduction zones underlay the volcanic arcs in early Mesozoic time.

As much as 14,000 feet (4270 m) of Upper Triassic tholeiitic lava, pillow lava, and aquagene tuff accumulated in the Insular Belt (Sutherland-Brown, 1966). Tentative paleomagnetic evidence for these flows suggests that they have moved northward about 30° of latitude with respect to the Triassic formations on the North American continent (Irving and Yole, 1972). Paleomagnetic data from 165 m.y. old Middle Jurassic plutons (Symons, 1971) that intrude the lava give pole positions consistent with those from other Jurassic formations from continental North America. Hence the Triassic rocks of Vancouver Island must have arrived at their present position relative to the North American continent by Mid-Jurassic time.

In each of the troughs volcanic-bearing facies merge into predominantly sedimentary facies. The clastics are largely volcanogenic or reworked pyroclastics and are characteristically poor in quartz. A fine-grained flysch-like sequence (Cultus Formation) extends northwestwards into the Insular Belt from the southern end of the Coast Geanticline. It is uncer-

tain whether this sequence represents accumulation in a trench or an arc-trench gap. Another flysch-like assemblage (Slocan Group) lies within and east of the southernmost part of the Omineca Geanticline. It may represent part of a basin lying between the craton and island arcs to the west. Quartzose terrigenous detritus between the volcanic arc in the southern-most Quesnel Trough and Omineca Geanticline may reflect local uplift of siliceous terrain in the latter during the Late Triassic.

In central British Columbia the occurrence of serpentine and chromite in basal Upper Triassic sediments east of the Pinchi Fault and the presence of clastic red beds farther southwest indicate the Late Triassic emergence of the Pinchi Geanticline and its contained ultramafic rocks.

After a brief hiatus of volcanism at the end of the Triassic volcanic activity continued again in the southern Cordillera in Early and Middle Jurassic whereas it ceased northwest of the Stikine Arch. The volcanism was largely explosive. Volcanic centres have been recognized in the Middle Jurassic of Queen Charlotte Islands but are inferred elsewhere as in the southernmost part of the Omineca Geanticline where Lower Jurassic volcanics lie unconformably on the upper Paleozoic and intertongue eastward with Lower Jurassic sediments.

Columbian Orogeny

Early Phases (Nassian)

The mid-Middle Jurassic was a time of deformation and uplift in the Western Cordillera (Fig. 6). Northeast-trending uplifts through the Stikine and Skeena Arches segmented the former northwesterly trending tectonic elements east of the Coast Geanticline into three successor basins: the Tantalus and Bowser Basins and the Tyaughton Trough.

During Middle Jurassic, the Omineca and Pinchi Geanticlines continued to be uplifted so that they merged into a single landmass and contemporaneous deformation culminated in the Omineca Geanticline — the core zone of the Eastern Fold Belt. Early Middle Jurassic and older strata were deformed prior to the emplacement of a discordant satellitic stock of the Nelson batholith dated by K-Ar at 164 m.y. (Nguyen at al, 1968). The deformation migrated eastward during succeeding phases of the Columbian orogeny and terminated in the deformation of the Rocky Mountain Foothills in the early Tertiary.

The Insular Belt apparently also underwent uplift, mild deformation, expressed as open folding and faulting of thick volcanic piles, and was intruded by several elongate, northwest-trending granodiorite plutons yielding K-Ar dates of about 165 m.y.

Mid-Mesozoic

The Tyaughton Trough is the only one of the three mid-Mesozoic successor basins east of the Coast Geanticline represented in the southern Cordillera. It received thick accumulations (up to 28,000 feet, 8,500 m) of interbedded sandstone, agglomerate, tuff, shale and conglomerate richer in quartz and K-Feldspar than the older sequences. Axial facies comprise flysch-like turbidites whereas marginal facies, locally unconformable on older rocks at the basin margin but most commonly separated from older rocks by faults, have an abundance of arenite, conglomerate, and plant fossils. The trough received considerable granitic debris from the western margin of the Pinchi Geanticline, now merged with the Omineca Geanticline. Granitic clasts first appeared in the early Late Jurassic (Oxfordian, Jeletzky and Tipper, 1968) but accumulated in abundance later in the late Early Cretaceous (Aptian and Albian). The youngest rocks of the trough are andesitic and basaltic flows and pyroclastics ranging from Albian to Cenomanian (early Late Cretaceous age).

Late Mesozoic-Early Cenozoic

In Late Cretaceous time a great deal of the Cordillera was land — mainly mountainous. Marine deposition continued into the early Late Cretaceous in the Tyaughton Trough and in the Georgia Basin of the Insular Belt (Fig. 5). Elsewhere non-marine clastics accumulated in local intermontane troughs, especially in the northern Rocky Mountain Trench and in the Sustut Basin of northern British Columbia.

In Latest Cretaceous and early Tertiary time a thick (13,000 feet, 3,980 m) assemblage of coal-bearing non-marine tongues of sandstone and conglomerate interfingered with marine shale and minor basic volcanics was deposited in the partly fault-bounded Georgia Basin. These clastics are partly faulted against older plutonic and volcanic rocks and partly lie unconformably on them on Vancouver Island in the Coast Mountains. Eocene clastics of the succeeding Bellingham Basin lie unconformably on Paleocene strata as well as on faults cutting them, and thus reflect tectonism and uplift of the northern Cascade Mountains in early Tertiary time.

Latest Cretaceous and early Tertiary volcanics are commonly associated with partly contemporaneous northerly trending normal faults and fault blocks. Grabens and tilted half-grabens may contain basal units of coarse clastics and coal beneath the volcanics. The volcanic rocks fall into distinct volcanic provinces: partly marine basalt and rhyolite accumulated on the Pacific Continental Shelf; and non-marine dacite and rhyolite in the central Interior Plateau; and non-marine andesite and trachy-andesite in the southern Interior Plateau. The volcanics of the mainland represent the scattered remnants of much more extensive sheets of ignimbrite and associated flows, domes, and breccias erupted from numerous fissures and vents. Some can be traced into subvolcanic plutons.

Late Cenozoic

Clastic marine sediments of Late Oligocene and Early Miocene age along the coast of Vancouver Island lie unconformably on older rocks and are unconformably overlain by Pleistocene sediments. Miocene sediments also occur on the submarine continental shelf and slope in anticlines, diapirs and fault blocks.

There is no record of Oligocene rocks on the mainland of the Cordillera but volcanic rocks generally regarded as Eocene may be partly Oligocene. Miocene silt, sand, and gravel lies along major valleys such as those of the Fraser River, Thompson River, and the southernmost Rocky Mountain Trench. These suggest that the major drainage routes were established by Miocene time, following a long interval of erosion.

Flat-lying plateau lavas of central British Columbia have yielded K-Ar dates of 10, 12, and 13 m.y. They overlie and interfinger with clastic sediments containing Late Miocene flora and locally some diatomite deposits. Olivine basalt with local rhyolitic and dacitic pyroclastics was erupted from fissures and shield volcanoes onto a gently undulating erosion surface that had relief of 1,500 to 2,000 feet (460 to 610 m). In the east the lavas apparently flowed into valleys bordering the Columbia Mountains and have since remained undisturbed. In the Coast Mountains to the west however, uplift in the Pliocene tilted the flows which now lie at elevations of as much as 8,500 feet (2600 m). Many Pleistocene and recent volcanoes lie within two narrow northerly trending belts and within a rather ill-defined westerly-trending one. Souther (1970) has stressed that the northerly-trend-

ing belts are parallel to the predominent direction of Tertiary normal faulting whereas the westerly trending belt is parallel to oceanic fracture zones and to east-west dykes in the western Coast Mountains.

Clastic Wedge Depositional Regime

Late Mesozoic-Early Tertiary

Syntectonic clastic wedge sequences consisting mainly of terrigenous detritus from the Cordillera were deposited from Late Jurassic to Paleocene time in foredeeps and basins on the flanks of the craton (Bally et al, 1966; Price and Mountjoy, 1970).

The clastic wedge in the southern Cordillera consists of the following sequences totalling 20,000 feet (6100 m) in thickness:

(1) a thick wedge of late Upper Jurassic and (?) early Lower Cretaceous non - marine coal - bearing sediments (Kootenay) and near-shore marine and non-marine clastics (Nikanassin), chiefly of resistant quartz, quartzite, chert, and micaceous detritus and subordinate volcanics and carbonate. Much of this sediment could have been eroded from strata overlying the succession now present in the Main Ranges of the Rocky Mountains.

(2) a thick wedge of dominantly non - marine clastics (Blairmore) of Lower Cretaceous age, which extends northeastward far onto the craton where it interfingers with marine sediments. The basal conglomerate overlaps Kootenay and older rocks northeastward and marks the end of the hiatus at the end of the Neocomian and Aptian. Clasts mainly of quartzose and siliceous sediments and subordinately of carbonate were probably derived from the succession now exposed in the Main Ranges or recycled from the Kootenay.

Clastics higher in the Blairmore packet are more heterogeneous, containing angular quartz, plagioclase, metasedimentary and volcanic fragments. Igneous pebbles ranging from dacite to rhyolite and diorite to granite probably represent volcanics and hypabyssal intrusives. These presumably were derived from igneous rocks correlative with those now found in the Omineca Geanticline. The uppermost clastics in the Blairmore are quartzose and cherty clastics that grade upward into alkaline pyroclastic rocks (Crowsnest).

(3) marine shales of early Upper Cretaceous age (Alberta Group) that extend as a blanket over the Plains. They thicken southwestward and interfinger with tongues of coarser clastics that are partly non-marine.

(4) a thick wedge of non-marine clastics of late Late Cretaceous and Paleocene age (Brazeau and Paskapoo) that extends as a thin blanket over the Plains where the lower part interfingers with marine shales.

Price and Mountjoy (1970) have concluded from a study of the westerly increase in the rate of thickening of the clastic wedge, and of the rate of increase of maximum size of clasts over several miles, that the source of the largest clasts must have been nearby. Thus the sediments accumulated in eastward migrating clastic wedges eroded from periodically advancing thrust sheets in what are now the Main Ranges and western Front Ranges of the Rocky Mountains. Price (1969) has argued that subsidence of the foredeep appears to be an isostatic effect that was induced by the loading of the crust due to large-scale mass displacements involved in the thrusting and folding of the supracrustal rocks. Fluctuations in the rate of deposition within the foredeep, which must correlate with variations in intensity of orogeny in adjacent parts of the Cordillera, indicate that the deformation occurred as a series of brief intense pulses spread over an interval of 100 million years from Late Jurassic to Paleocene.

Post-orogenic clastics in the Rocky Mountains

Latest Eocene or Earliest Oligocene sediments (Kishenehn Fm.) 6,600 feet (120 m) in thickness, were deposited in a structural basin on the down-thrown side of the Flathead normal fault. The eastern facies consists of coarse conglomeratic clastics derived from Paleozoic and Precambrian rocks of the upthrown block. The western facies comprises finer clastics, marl, and lignite. Sedimentation apparently took place simultaneously with displacement of the fault.

These sediments lie with angular unconformity on strata deformed during the terminating phase (Laramide?) of the Columbian orogeny. They therefore provide an upper limit for dating the underlying Front Range structures of the southeastern Canadian Rocky Mountains.

STRUCTURAL GEOLOGY OF THE SOUTHERN CANADIAN CORDILLERA

Introduction

The structural profile (Fig. 7) across the southern Canadian Cordillera is featured by two intensely deformed zones — the Eastern and Western Fold Belts — which in gross aspect represent sections across downward-narrowing prisms of opposing asymmetry, separated by a relatively weakly deformed Intermontane Zone in which the surficial deformation has been slight.

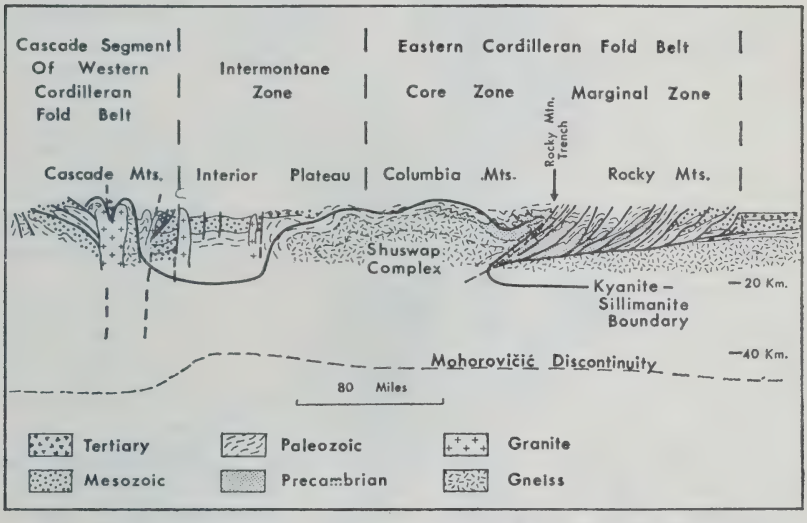
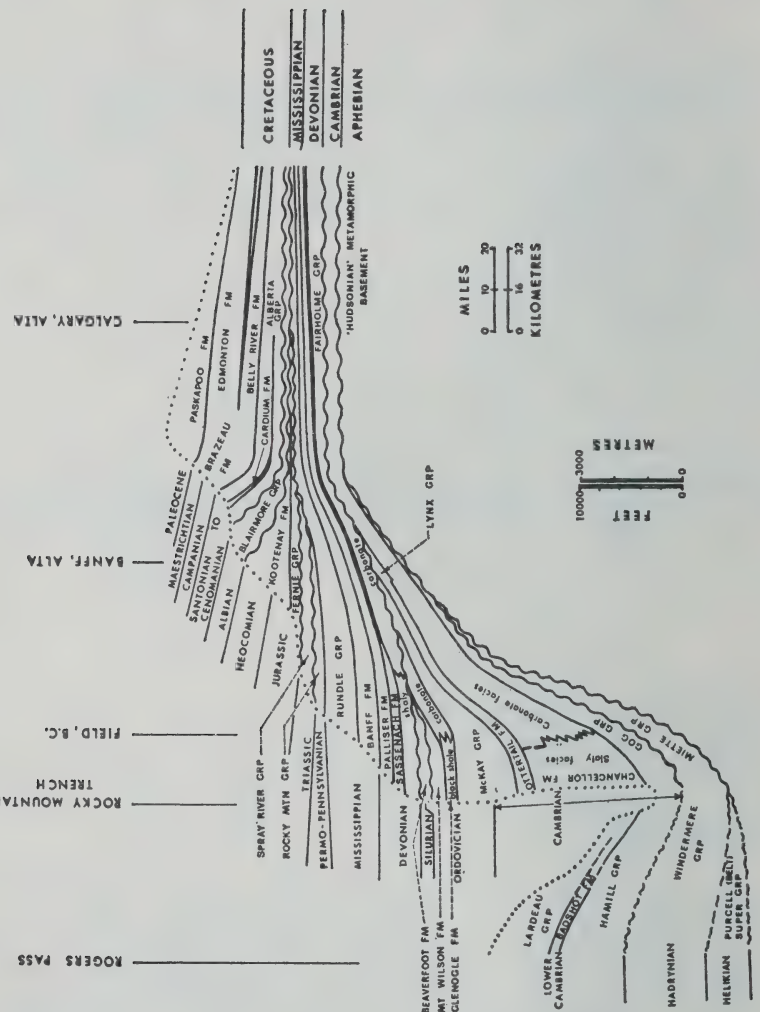


Fig. 7. Diagrammatic structure section, southern Canadian Cordillera (Wheeler, 1970).

The Eastern Fold Belt is composed of a core zone characterized by metamorphic rocks and a Foreland thrust belt to the east featured by "thin-skinned" deformation. The core zone is typified by isoclinally and commonly recumbently folded metamorphic rocks of upper amphibolite grade (staurolite-kyanite-sillimanite) that may contain mobilized crystalline basement. The plastic deformation of the metamorphic infrastructure contrasts with the brittle deformation of the supracrustal rocks. The Foreland thrust belt (Rocky Mountains) is dominated by surficial thrusting directed northeastward over a passive basement at the edge of the


CRETACEOUS
MISSISSIPPIAN
DEVONIAN
CAMBRIAN
APHEBIAN
CALGARY, ALTA
BANFF, ALTA
FIELD, B.C.
ROCKY MOUNTAIN TRENCH
ROGERS PASS
MILES
KILOMETRES
METRES
FEET
'HUDSONIAN' METAMORPHIC BASEMENT
FAIRHOLME GRP
PASKAPOO FM
EDMONTON FM
BELLY RIVER FM
ALBERTA GRP
BRAZEAU FM
CARDIUM FM
PALEOCENE
MAESTRICHTIAN
CAMPANIAN
SANTONIAN
CENOMANIAN
TO
ALBIAN
BLAIRMORE GRP
KOOTENAY FM
HEOCOMIAN
JURASSIC
FERNIE GRP
RUNDLE GRP
BANFF FM
PALLISER FM
SASSENACH FM
LYNX GRP
COLUMBIA
SPRAY RIVER GRP
ROCKY MTN GRP
TRIASSIC
PERMO-PENNSYLVANIAN
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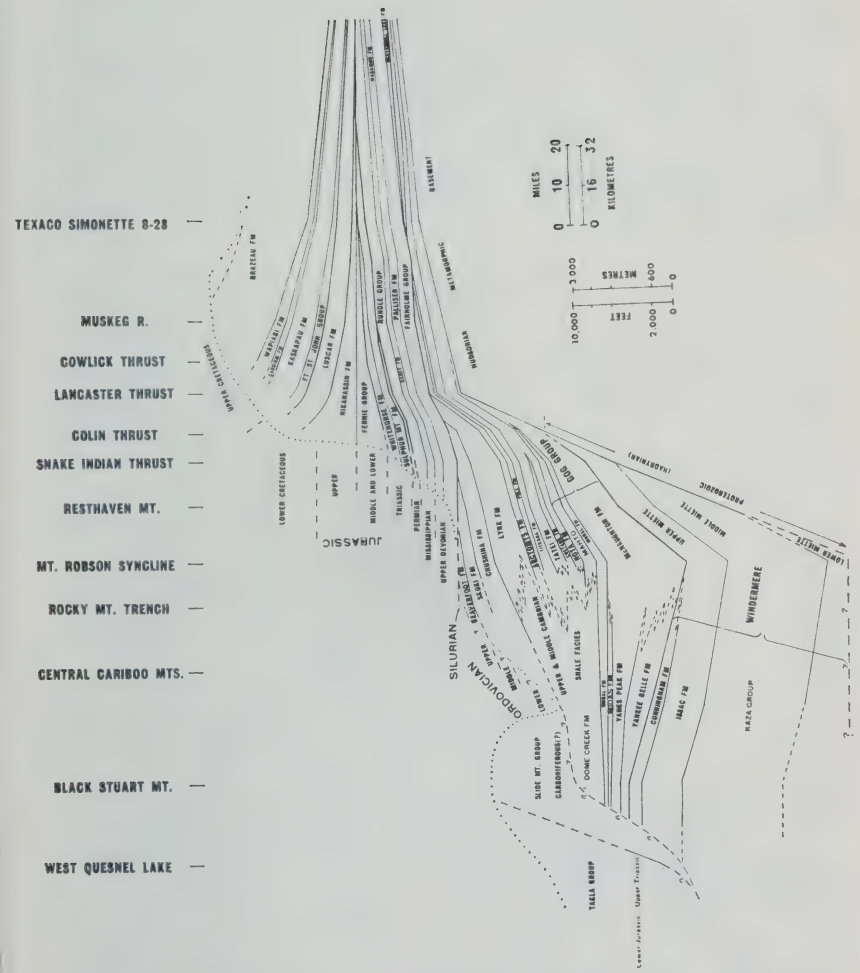

Fig. 9. The wedge of supracrustal rocks lying on Hudsonian basement from the upper Smoky River westward across the Cariboo Mountains west from McBride, about Latitude 53°20′ (E. W. Mountjoy).

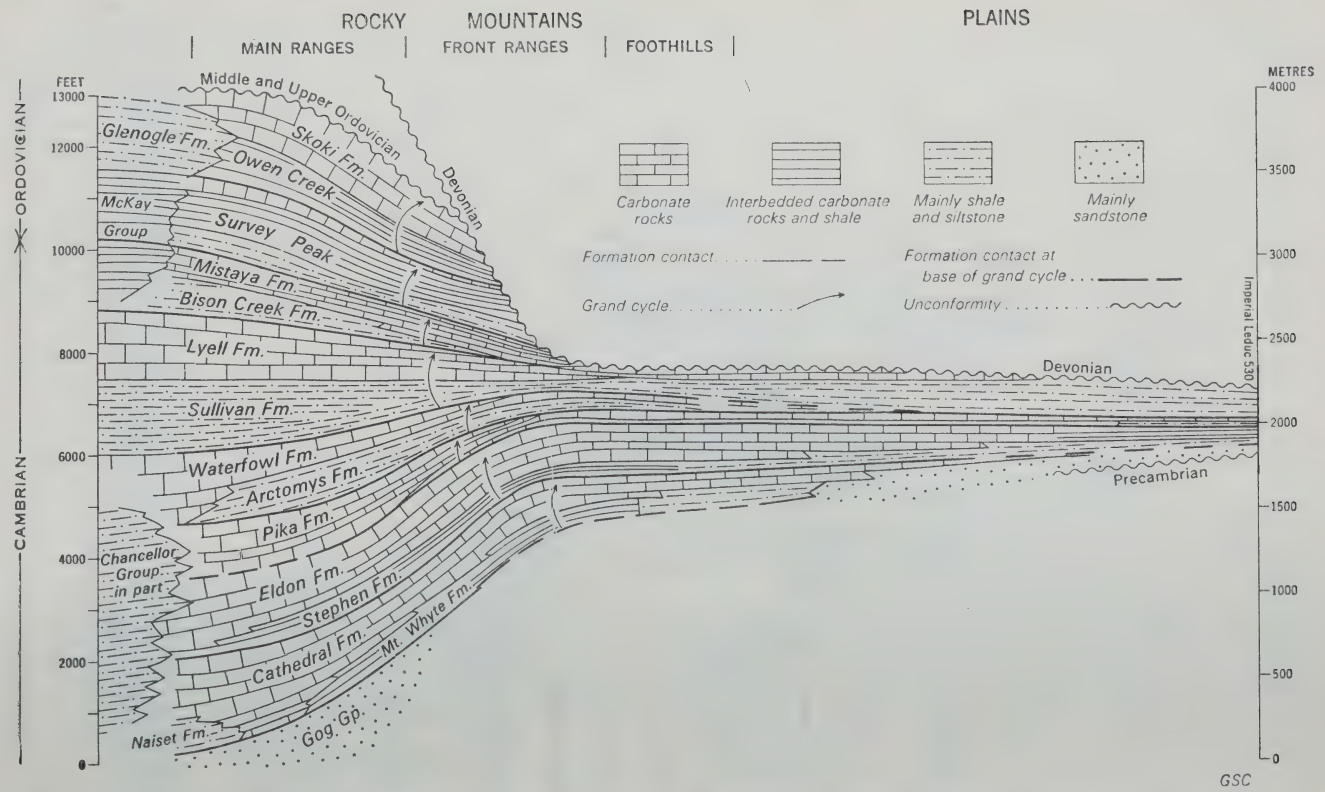

Fig. 10. Schematic restored stratigraphic section of Cambrian and Ordovician rocks (modified after Aitken, 1966).

North American craton. A model is proposed (Price and Mountjoy, 1970) whereby surficial thrusting, when viewed at a large scale, constitutes a type of "plastic" flow that involves large-scale strain without loss of cohesion. The bulk strain in the Eastern Fold Belt reflects a buoyant upwelling of the core zone and lateral gravitative spreading, mainly to the northeast relative to the craton, but also, subordinately, towards the southwest. The upwelling in the core zone, however, was not particularly great because Lower Cambrian strata lie at roughly similar elevations across the entire Eastern Fold Belt. On the other hand, the interior of the core zone was the site of a thermal upwelling which resulted in more ductile deformation at relatively high stratigraphic levels.

The Western Fold Belt is composed of the Cascade fold belt south and southeast of the Fraser River and the Coast Crystalline complex to the north. The Cascade fold belt is marked by easterly and westerly spreading thrust faults that root near a metamorphic core, also featured by upper amphibolite grade (kyanite-sillimanite). Ultramafic rocks are associated with thrust faults on both sides of the segment. Those on the west side are locally folded and contain metamorphic rocks of blue schist facies and slivers of probable pre-Devonian basement. The bulk strain of the Cascade fold belt reflects movement of material upwards and significantly more to the west than to the east and thus is opposed to that of the Eastern Fold Belt. Structural elements of the Cascade fold belt can be traced northwestward into the Coast Crystalline complex which is characterized by far more extensive areas of plutonic rocks and is interpreted as reflecting a deeper structural level of the Western Fold Belt than the Cascade fold belt. Structures in the southern part of the Coast Crystalline complex are nearly vertical.

The Intermontane Zone has undergone negligible surficial shortening in the Mesozoic volcanic sequence and has remained relatively stable since Early Jurassic time, except for repeated jostling along faults. Upper Paleozoic rocks, having some similarities to ophiolite suites, contain mélange zones, and are strongly and irregularly deformed. Block faulting associated with local continental basins and contemporaneous volcanism was important in early Tertiary time. The block faulting extended eastward as far as the western Rocky Mountains.

Relatively mild deformation of the Insular Zone, like that of the Intermontane Zone, is dominated by faulting. Major

transcurrent faults have been recognized along the eastern margins of the Western Fold Belt and are probably present elsewhere in the Intermontane and Insular Zones.

Eastern Cordilleran Fold Belt

Marginal Zone (Rocky Mountains)

The characteristic style of deformation in the southern Canadian Rockies is thrust faulting and concentric folding. The structurally anisotropic well-layered strata of the Rocky Mountains are deformed by numerous generally southwest-dipping, concave-upward, locally folded thrust faults. The sedimentary rocks have been stripped along the layering from their underlying basement. They have been thrust northeastward relative to the basement, with some accompanying concentric folding, for as much as 125 miles (200 km), to where they are now stacked up in a series of thrust sheets on the edge of the North American craton. The stacked thrust sheets have produced surficial tectonic thickening of 5 miles (8 km) above the passive basement.

The structural style and density of thrusting are related to the competence and structural anisotropy of the rocks, which in turn, are governed by the stratigraphic level and facies exposed. Thrust faults are thus most numerous in the weak Cretaceous rocks of the clastic wedge exposed primarily in the Foothills of the Eastern Rocky Mountains. They are more widely spaced in the Front Ranges, dominated by the Devonian to Jurassic miogeoclinal-platform sequence, and are comparatively rare in the thick competent lower Paleozoic beds that comprise the eastern Main Ranges. The penetrative slip folding in the shaly, incompetent facies of Cambrian and older rocks of the Western Main Ranges contrasts with the concentric folding of the more structurally anisotropic layering in the ranges to the east.

The Malton gneiss, in the hanging wall of the Purcell Fault, has locally overridden Cambrian and older rocks in the Rocky Mountains along the Rocky Mountain Trench near Valemount. The structures in the Main Ranges are apparently related to the northeastward emplacement of the gneiss, and perhaps also to deformation of the basement beneath the sedimentary pile. An enveloping halo of metamorphism, dated as late Early Cretaceous (111 m.y. — Price and Mountjoy, 1970) surrounds the gneiss. Structures in the Front Ranges and Foothills do not reflect the influence of the emplacement of the gneiss as do those of the Main Ranges,

hence they are inferred to have formed later than those in the Main Ranges.

South from Valemount the Purcell Fault progressively diverges from the more westerly structural trends of the Rocky Mountains thus truncating structures of the Western Ranges. These ranges are composed of transverse — and strike — faulted lower Paleozoic rocks overturned to the southwest on the southwest limb of the fan-shaped Porcupine Creek anticlinorium.

The deformation in the Rocky Mountains took place during late Mesozoic and early Tertiary and is essentially a continuation of that begun earlier in the Eastern Core Zone. The first thrust faults apparently formed in the western Rockies, probably in Late Jurassic time, and progressively younger ones developed farther east in sequences overridden by the earlier-formed thrust sheets. Thrusting ended in the early Tertiary in the Foothills. Wherever the younger, lower thrust sheets cut up-section, or stepped from one incompetent horizon to a higher one, or were folded, the older, overlying thrust sheets were also rotated or folded. The penetrative array of thrust faults are interleaved and mechanically interlocked, thus, where the stratigraphic separation across an individual thrust fault decreases and ultimately reaches zero, the separation across adjacent or nearby ones increases proportionately. Therefore, the aggregate displacement across a group of thrust faults appears to remain relatively constant. Apparently there has not been a loss of cohesion of the mass during thrusting and accordingly, at gross scale of observation, the overall structural pattern reflects a type of "plastic deformation" or flow that has resulted in northeastward shortening and vertical thickening.

The last structural event was early Tertiary block faulting related to northeastward extension following thrusting. Northwesterly trending southwest-dipping normal faults are consistently later than the thrust faults. Some pass into thrust faults and, as demonstrated by deep drilling and seismic reflection data, flatten with depth and apparently do not cut the crystalline basement.

Eastern Core Zone (Columbia Mountains)

The core zone of the southern part of the Eastern Fold Belt comprises several structural elements. The Shuswap Metamorphic complex in the heart of the core zone is flanked on the north by the Cariboo Mountain sub-province and on

the east by the Kootenay Arc (Fig. 4). The latter is flanked on the east by the Purcell anticlinorium.

The west-dipping Purcell Fault truncates structures on both sides of the Rocky Mountain Trench. On the east this fault progressively truncates Western Ranges and Main Ranges structures and on the west truncates Purcell anticlinorium, Dogtooth Range, northern Selkirk Mountains, northern Monashee, and southeasternmost Cariboo Mountain structures of the Eastern Core Zone.

Purcell Anticlinorium -

The Purcell anticlinorium, underlain mainly by Proterozoic Purcell sedimentary rocks, is steep-sided and flat-topped in cross-section (Fig. 3). Several eastward overturned and faulted folds form part of the box-shaped structure thrust across the Rocky Mountain Trench near latitude 49°30′. The anticlinorium is composed of several north-plunging segments, separated by transverse faults that are apparently as old as Cambrian. These faults may have acted as oblique thrusts (Leech, 1962) or as folded thrusts (Dahlstrom, 1970). Some folds appear to have been formed prior to the emplacement of a granitic stock more than 1200 m.y. old.

Late Proterozoic Windermere and Lower Cambrian sediments of the Dogtooth Range in the northwesternmost part of the anticlinorium are deformed by several major, mainly west-dipping, locally folded thrust faults and later normal faults that telescope a series of southeast plunging folds. The axial surfaces of the folds dip southwest. The geometry of the folds, which are concentric, is strongly influenced by the thick Lower Cambrian quartzite. Simony and Wind (1970) suggest that the thrusting took place in two episodes: an earlier phase, congruent with the folds, that was governed by anisotrophy of the bedding, and a later phase, of which the Purcell and Dogtooth Faults are examples, which originated after the folding and late in the episode of metamorphism that affected the western Dogtooth Range. The planes of anisotrophy for the later thrusting may have been controlled in part by steeply dipping cleavage in slate and phyllite.

Northern Selkirk Mountains - Kootenay Arc

The Kootenay Arc is an arcuate belt of complexly deformed rocks ranging in age from Proterozoic to Middle Jurassic. It extends from south of the International Boundary into the Selkirk Mountains and over much of its length merges with the west side of the Purcell anticlinorium. At its northern

end, at about a structural depression near the Trans Canada Highway, it merges with structures of the Northern Selkirk Mountains that lie northeast of the Shuswap Metamorphic complex. The Selkirk structures also form the southern part of a broad culmination extending northwest into the Cariboo Mountains. The Selkirk-Kootenay Arc belt is featured by westerly-directed or back folded structures at its northern and southern ends, but in its central part, east of Kootenay Lake, the structures are directed eastward. It also contains a belt of metamorphic rocks that diverged southeastward from the Shuswap Metamorphic complex, across the southern Selkirks, southerly through a metamorphic depression into a second metamorphic culmination along the Kootenay Arc east of upper Kootenay Lake.

The structure of the belt is complex: the result of polyphase deformation that began in mid-Paleozoic time and was essentially completed by mid-Jurassic time. The earliest folds (Phase 1) are highly attenuated isoclinal folds — generally mesoscopic — in which both limbs are commonly deformed by later folds. Phase 1 folds in the central part of the belt have variably plunging northwesterly trending axes, those in the western Selkirks north of the Trans Canada Highway plunge northeast, and finally Phase 1 folds in the northwesternmost Selkirks plunge west. Some of these folds have axes that curve as much as 90°.

The Phase 1 folding was apparently accompanied by large-scale *décollement* thrusting in mid-Paleozoic since:

(1) The earliest foliation in the belt — presumably related to the earliest folding — was developed prior to Upper Mississippian sedimentation, because conglomerate of this age contains variously oriented, foliated boulders of and lies with angular unconformity on the Broadview Formation.

(2) The Broadview Formation is probably of Windermere age and therefore must form a huge allochthone lying on lower Paleozoic strata;

(3) Although Phase 1 folds are developed within the allochthone and in the lower Paleozoic strata beneath it they do not fold the basal contact of the allochthone. Thus the thrusting must have occurred during or after the Phase 1 folding but not before. The thrusting, however, was completed before Phase 2 folding commenced because both Phase 1 folds and the allochthone itself are deformed by the later folding;

(4) In order that Broadview strata could have been overlain unconformably by the Upper Mississippian beds the Broadview must have been thrust over the lower Paleozoic in post-Early Cambrian — pre-Upper Mississippian (possibly in Late Devonian or Early Mississippian time) when large-scale *décollement* thrusting took place in the United States Cordillera during the Antler orogeny.

The Phase 2 folds generally trend northwesterly and are similar in style. They are more open than Phase 1 folds and are the most obvious flexures in the region and have the greatest influence on the map pattern. The axial planes of Phase 2 folds, however, are warped by Phase 3 folds that produced westward rotation and back folding accompanied by westward-directed slides, reverse, and thrust faults. The backfolding thus produced fan structures, of which the Selkirk fan structure is the largest. The back folding is most severe in the western part of the Selkirk fan structure opposite Frenchman's Cap dome and the Clachnacudainn salient. There originally westerly trending Phase 1 folds that had southerly dipping axial surfaces have been rotated so that the axial surfaces now dip northeast and the axes plunge northeast. The axis of rotation plunges southeastward and the rotated folds form the upper limb of the backfold. The eastern margin of the Shuswap complex is marked by a cataclastic and shattered zone. North of the Selkirk backfold this zone truncates Frenchman's Cap dome and greenschist facies rocks lie against the gneisses in the core of the dome. It appears that the fan structure developed at a late stage by progressive and increased pinching between the gneisses of the Shuswap Metamorphic complex to the west and the Precambrian basement to the east that is inferred to dip more steeply westward at about the Rocky Mountain Trench. All the folding appears to have been completed prior to the emplacement of discordant granitic rocks dated by K-Ar methods at 164 m.y. old — although some older granitic rocks appear to have been involved in Phase 2 deformation.

Cariboo Mountains

The northern Cariboo Mountains (Campbell, 1970) comprise several anticlinoria and synclinoria that plunge generally northwestward from a structural culmination near the Big Bend of the Columbia River. From this locality the Selkirk-Purcell metamorphic belt diverges southeastward from the Shuswap Metamorphic complex. The grade of meta-

morphism is mainly higher in the anticlinoria than in the synclinoria.

The region displays progressive structural and metamorphic transitions from "infrastructure" to "suprastructure". The infrastructure, comprising the upper Precambrian rocks of the Premier anticlinorium, is characterized by staurolite-kyanite grade of metamorphism and displays polyphase folding. Isoclines are themselves arched across an antiformal axis. The isoclines are interpreted as flow folds in which compositional layering and schistosity are parallel. This zone passes upward through a transitional simple anticline in which metamorphic foliation parallels bedding, into a zone of large similar or composite folds with prominent axial-plane foliation. The axial surfaces of the similar folds are arranged in a broad fan so that they are more or less normal to the surface of the transition anticline and to the axial surfaces of the structurally lower isoclines. The uppermost part of the structural progression, the suprastructure, is a zone of brittle deformation in which relatively competent and essentially unmetamorphosed rocks of Latest Precambrian and Early Cambrian ages are broken into many fault blocks, tilted, and locally concentrically folded.

The infrastructure can be interpreted as a region of substantial crustal shortening whereas the brittle suprastructure, which results from a high level response to the same stresses that produced the infrastructure at depth, indicates that major crustal shortening was not significant in the Eastern Core Zone. The close relationship of the intensity of deformation to the grade of metamorphism suggests that thermal energy is a most significant factor in the development of folds. The role of mechanical energy, in the sense of regional "compressive stress" is difficult to assess (Campbell, 1971).

Shuswap Metamorphic Complex

The Shuswap Metamorphic complex, with rocks generally in the upper amphibolite facies, contains in its eastern part a series of gneiss domes at about 50 mile (80 km) intervals (Fig. 2). The domes are characterized by cores of migmatitic granitoid gneiss enveloped by mantles of metasedimentary gneiss and, locally, nepheline syenite gneiss fringed with metasedimentary gneiss which is riddled with pegmatite. The metasedimentary gneiss contains a lower sequence that is generally similar in lithology, though not in detail, to the Lower Cambrian Hamill Quartzite — Badshot Limestone succession in the Kootenay Arc and an upper

sequence broadly resembling the Carboniferous (?) and Permian Milford Group. In places strata as young as Late Triassic or Early Jurassic can be traced into the complex.

The domes feature interfolding of the mantling zone gneisses and the core migmatites; an extreme example of which is the antiformal syncline draped about the eastern slopes of the culmination of the Thor-Odin dome (Reesor, 1970).

Mesoscopic structures show contrasting styles not only with respect to structural level but also at roughly the same level from one dome to another. Single folds show variation in shape and style. Structures developed at deeper levels are not reflected in the low-grade cover rocks and *vice versa*. For example, in the depths of the Thor-Odin dome recrystallization outlasted deformation, whereas near the eastern margin of the dome, movement and deformation outlasted recrystallization to produce a cataclasite zone.

The principal deformation and metamorphism of the complex occurred in post-Late Triassic or Early Jurassic time. It began in the eastern part of the complex with intense metamorphism and migmatization accompanying large scale east-west trending interfolding of the core and mantle. Such folds permitted the local rise of migmatite and granite gneiss, concentrating hotter material beneath the east-west anticlines. This concentration resulted in local diapiric uprise of the migmatitic core synchronous with a northwesterly arching along the eastern edge of the complex. The final deformation consisted of warping and development of some northwest-trending folds.

It has been speculated that the core gneisses may represent Hudsonian basement but substantial evidence has not yet been found to support this idea. Reesor (1970), on the other hand, concludes that the core gneiss could have been derived readily from Windermere pelitic and semipelitic sedimentary rocks. The overlying quartzite-carbonate sequences remained resistant to migmatization. Thus metamorphism, rather than homogenizing the assemblages, served only to emphasize the original differences.

Transitional Zone between the Eastern Core Zone and the Intermontane Zone

West of the Shuswap complex, polyphase structures of varying style are developed at different levels in upper Paleozoic and possibly lower Mesozoic formations that, in general,

increase in metamorphic grade from low greenschist to upper amphibolite facies with stratigraphic depth. This structural zone is transitional between the complex structure of the Eastern Core Zone and simple structure of the Intermontane Zone.

Fyson (1970) identified four phases of deformation prior to the emplacement of a pluton dated by K-Ar methods at 127 m.y. (Early Cretaceous). The earliest structures are rare mesoscopic isoclinal folds. Phase 2 folds occur mainly in gneiss and schist as recumbent folds and rarely in phyllite and argillite where they are accompanied by an axial-plane cleavage. They converge west of the Shuswap complex towards a north-trending synform and, farther west, diverge from an antiform that trends northwesterly towards a gneiss dome. The later Phase 3 and 4 folds are distinguished from the earlier folds by having more open profiles of variable shapes and by having axial surfaces at high angles to the general attitude of the foliation and layering. Fyson believes that the variation in structural style between the upper and lower levels is not due to the change in style of a single generation of folds, rather that it results from the intensity of development of structures of different generations at different levels. During the early phases of deformation the lower levels were relatively plastic and spread laterally while the less plastic higher level rocks rode *en masse* as thrust sheets. Later phases affected both levels but the higher, more anisotropic rocks folded more readily.

Intermontane Zone

The southern part of the Intermontane Zone consists of a medial belt of moderately and locally irregularly deformed upper Paleozoic (Cache Creek Group) basic volcanics, ultramafics, pelites, mélange, ribbon chert, and limestone. The detailed structure and habit of the assemblage is not known. These strata are overlain apparently unconformably by widespread, gently folded and faulted volcanic rocks of Late Triassic age (Nicola Group). The Triassic rocks are intruded by several large and small plutons, many of which were emplaced in Late Triassic and Early Jurassic time, although some are younger. The western part of the zone contains small areas of Lower and Middle Jurassic clastics, containing debris of Triassic-Jurassic granitic rocks. Also present are gently deformed Lower Cretaceous volcanic rocks. Patches of Cenozoic volcanic rocks lie unconformably on all older rocks.

Detailed studies by Schau (1970) near Nicola Lake indicate that the Nicola Group, which was deformed mainly in the earliest Jurassic, was folded by flexural-slip in a high-level environment and that the associated strain was less than 5 per cent. Locally, near plutons, greater strain caused the development of cleavage and stretching of pebbles. Elsewhere, stress was relieved by faulting. Movement took place during the Early Jurassic along northerly and westerly trending faults and continued intermittently along the northerly trending faults in Cenozoic time when Tertiary volcanic rocks were extruded along them.

Shau's studies reveal that no more than 2 miles (3 km) of uplift and erosion have taken place to expose the rocks now at the surface. The relative immobility during the Mesozoic of the uppermost crust in the Intermontane Zone is in contrast with the mobility of the bounding fold belts. Paleomagnetic studies (Symons, 1971) on the Triassic-Jurassic granitic plutons, however, suggest that the plutons were rotated 40° clockwise between Early and Late Jurassic time, perhaps by right-lateral movement on northwest-trending faults within or bounding the Intermontane Zone.

Western Cordilleran Fold Belt

The southernmost part of the Western Fold Belt is composed of the southern part of the Coast Crystalline complex (Fig. 4) and the Cascade fold belt lying en-echelon east and south it. The northern part of the Cascade fold belt, lying within British Columbia, includes an Axial zone of upper Paleozoic sediments whose core was metamorphosed in earliest and again in late Mesozoic time and invaded by Late Cretaceous intermediate-level and late Tertiary high-level granitic plutons. The Axial zone is bounded by belts of Mesozoic clastic and subordinate volcanic rocks. Lower Tertiary clastics are restricted mainly to the north-trending Fraser River Fault zone, whereas small patches of Tertiary volcanics occur here and there.

The principal structures in the Cascade fold belt are westerly and easterly spreading thrust faults that root near the Axial metamorphic zone (McTaggart, 1970). Those in the west, dipping gently southeast and associated with northeast-trending recumbent folds, are possibly part of a westward-convex salient that extends into Washington State where the thrust faults appear to be broadly folded (Misch, 1966). Those in the east dip steeply west and strike northwesterly. The most important thrust faults on both sides

of the fold belt have ultramafic rocks associated with them. Those in the west near the International Boundary contain metamorphic rocks of blue-schist facies and tectonic slivers of crystalline rocks similar to nearby pre-Devonian crystalline basement.

McTaggart (1970) proposed that the Coast Crystalline complex represents a deeper structural level than the Cascade fold belt, within the same orogen. The Cascade fold belt represents the upper levels, only slightly eroded. The Coast Crystalline complex to the northwest, made up largely of granitic plutons, with numerous roof pendants, reveals the deeper levels. The overlying diverging thrust plates have stripped off and only the steeply dipping root zones of the thrusts and the central metamorphic axis can be followed northwest into the plutonic zones where structures generally strike northwest.

The Axial metamorphic zone rose in early Late Cretaceous time and thrusts developed within the marginal sedimentary packets and progressively migrated outward. Thrusting ceased by mid-Late Cretaceous. Some right-hand transcurrent movement took place on faults along the east side of the Cascade fold belt northwest and southeast of the Fraser River. Later events involved widespread emplacement of granitic plutons in the Late Cretaceous and uplift of the Coast Crystalline complex in the early Tertiary. These events were overlapped in time by intermittent activity along the Fraser River Fault zone from late Mesozoic through early Tertiary and were followed by a granitic intrusion in the late Tertiary.

EXCURSION

Day 1 — Marginal Zone — Eastern Cordilleran Fold Belt

The route across the Canadian Rocky Mountains through the Kicking Horse Pass (Figs. 2 and 3) provides one of the most complete and best exposed sections through the foreland thrust and fold belt of the North American Cordillera. The differing structural styles evident across this region have resulted from changes in the mechanical response to deformation within a northeasterly tapering wedge of sediments.

The Sedimentary sequence

The sedimentary sequence (Figs. 8 and 9) forms a supracrustal wedge consisting of:

A — a prograded continental terrace (miogeocline to platform) of Middle Proterozoic to Late Jurassic age, and

B — a clastic wedge of Late Jurassic to Paleocene sediments (molasse in a broad sense) restricted to the eastern part of the belt.

These sequences overlap northeastwards onto the Hudsonian crystalline basement of Early Proterozoic (Aphebian) metamorphic and plutonic rocks which extends under the Interior Plains from the Churchill Province. The sedimentary wedge has been stripped from the southwesterly sloping basement surface, and displaced up onto the flank of the craton along a myriad of interleaved and overlapping thrust faults.

The miogeocline - platform sediments consist mainly of carbonates, shales, and mature sandstones and is more than 45,000 feet (14 km) thick It is divisible into six distinct assemblages (Figs. 8, 9, 10).

1) Purcell (Middle Proterozoic or Helikian)
2) Windermere (Late Proterozoic or Hadrynian)
3) Gog Group (Late Proterozoic and Early Cambrian)
4) Early Paleozoic carbonate shelf (Middle Cambrian to Silurian)
5) Middle to late Paleozoic carbonate shelf (Upper Devonian to Permian)
6) Early Mesozoic clastics (Triassic to Middle Jurassic)

The Purcell System does not outcrop along the route traversed, but occurs at the surface in the region to the south near the International Boundary, in the Purcell anticlinorium. Purcell sediments exhibit abundant shallow water features suggesting accumulation as a prograding deltaic complex with a maximum exposed thickness of 45,000 feet (14 km) (Price, 1964). Purcell deposition was followed by deformation and regional metamorphism termed the East Kootenay orogeny.

The Windermere System includes the oldest rocks exposed in both the Kicking Horse and Yellowhead Pass regions of the Main Ranges. The Windermere consists mainly of a heterogeneous mixture of immature, poorly sorted clastic sediments derived from the craton. This group thickens rapidly westward and northwestward from about 3,000 feet (910 m) near Golden to over 21,000 feet (6,400 m) near Mount Robson. The type of depositional regime is uncertain, but it is a continuation of the Purcell sedimentary

wedge and probably deposition of sediments took place rapidly in subtidal envirnments of moderate depth permitting little opportunity for sorting and reworking.

The Gog Group represents the continued development of the sedimentary wedge and a return to shallow water conditions with abundant reworking and sorting yielding quartz rich sandstone. It outcrops only in the western Front Ranges and Main Ranges. The sandstones follow the same thickness trends as the underlying Windermere rocks, thickening northwestward.

The early Paleozoic carbonate shelf reflects an abrupt change in facies from dominantly clastic sediments of the Gog Group to mainly carbonate sediments, presumably as a result of bevelling of the Canadian Shield. The carbonates overlapped and buried the cratonic interior. The southwesterly thickening of the supracrustal sedimentary wedge is partly a result of this overlap, but also involves substantial thickening within individual stratigraphic units. In conjunction with the thickening, an important facies change occurs where shallow water massive carbonates change abruptly southwest into calcareous shales and slates near Field and elsewhere in the western Main Ranges. This facies change has a profound effect on the structural style (see below).

The middle and late Paleozoic carbonate shelf is separated from the underlying early Paleozoic sequence by an important unconformity that represents widespread erosion that progressively bevelled strata towards the craton. In addition a hinge zone is evident above the Bourgeau Thrust (near the Front Ranges-Main Ranges boundary); to the northeast is a platform facies in which rock units are both thinner and fewer in number, whereas to the southwest is a miogeocline in which more of the record is preserved. The Upper Devonian and Carboniferous carbonates form extensive porous reservior rocks in the Alberta subsurface. Reef complexes developed during the early Upper Devonian and locally modify the structural style (contrast Jasper and Bow Valley section - Figs. 8 and 9).

The early and middle Mesozoic clastics derived from the craton to the east consist of shallow water shelf sequences which thicken southwestward.

The Clastic Wedge Sequence

The Late Jurassic to Paleocene clastic wedge sequence is preserved only in the eastern Front Ranges, Foothills and

Interior Plains. The clastic wedges represent a profound change in the character and provenance of the supracrustal sedimentation and mark the onset of orogeny in the eastern part of the Cordillera. Several distinct unconformity-bounded clastic wedges suggests a northeasterly migrating foredeep (Bally *et al.*, 1966). Examining the clastic wedges with respect to a palinspastic reconstruction indicates that the source of much of the clastic detritus lay within the Rocky Mountain thrust sheets, just west of the limit of preservation of the individual clastic wedges (Price and Mountjoy, 1970). The Lower Cretaceous and latest Upper Cretaceous to Paleocene parts are mostly non-marine, whereas the early Upper Cretaceous is predominantly marine. Deposition in the foredeep is related to subsidence which apparently correlates with variations in intensity of orogeny to the west and corresponding loading on the crust (Price, 1969). Sand bodies enclosed in silts and shales form stratigraphic traps for hydrocarbons in the up-dip portion of the Alberta basin.

Structure

A complete transition occurs across the Eastern Cordilleran Fold Belt from essentially brittle deformation in the foreland margin of the unmetamorphosed sedimentary wedge of the Rocky Mountains to large-scale penetrative flow in the hot ductile rocks of the mobile infrastructure in the Columbia Mountains metamorphic core zone of the fold belt (Fig. 3). Thrust faults are the dominant tectonic elements in the structure of the Rocky Mountains. They form a complex of interleaved and overlapping slip surfaces along which the well-layered and anisotropic sedimentary wedge of supracrustal rocks was stripped from its basement and displaced northeastward, up the flank of the craton, to where it is now stacked as imbricate thrust slices and associated folds of the Rockies. Variation in rock type and structural level in the sedimentary wedge during deformation gave rise to variations in structural style, frequency and magnitude of thrusts, and size, shape and orientation of folds, etc.

The linear topography of the Foothills reflects to some extent the steep imbricate thrust slices and folds of Cretaceous strata which occur above relatively flat, thin thrust sheets of late Paleozoic carbonates at depth (see cross-sections, Fig. 3). In contrast, the Front Ranges, at a slightly deeper structural level, consist of several relatively simple, southwesterly dipping homoclinal thrust sheets which flatten downward above the basement. The rocks in these

thrust sheets are still part of the thin platform sequence with a cover of clastic wedge deposits.

A more obvious change in structural style occurs in the eastern Main Ranges where the early Paleozoic carbonate succession of the miogeocline facies and underlying Lower Cambrian and Windermere clastics form large open folds within a few simple, flat thrust sheets. Locally, southwesterly dipping normal faults are abundant. This part of the sedimentary cover is thicker and more competent than in the Front Ranges and the structural level is deeper. In the western part of the Main Ranges there is a pronounced change in structural style at the same structural level due to the change to incompetent calcareous shale and slate from massive Middle and Upper Cambrian carbonate. The development of tight folds and slaty cleavage in large anticlinoria, in which the cleavage and axial surfaces of subsidiary folds are arranged in a fan suggest a plastic flow pattern.

Day 1: Calgary To Golden

0.0 Calgary.

STOP 1-1 *Western Edge of Plains*
14.5 miles
(23.2 km)

This stop provides a view westward across the Foothills to the Front Ranges of the Rocky Mountains. Both the Foothills and the Front Ranges form an array of steeply southwest-dipping thrust slices and sheets (see cross-section, Fig. 3). The western margin of the Plains is marked by the first fold or thrust fault which reaches the surface. East of this point is a thick sequence in the order of 5,000 feet (1520 m) of Late Cretaceous and Tertiary nonmarine sediments derived from erosion of parts of the Foothills and Front Ranges. These Tertiary deposits are poorly exposed and are overlain by extensive Pleistocene glacial lacustrine deposits.

The thrust faults extend down to a *décollement* zone just above the Precambrian basement They involve upper Paleozoic strata and gradually become more gently dipping at depth. The Jumping Pound gas field (mile 16.0) and other Foothills gas fields produce from the Turner Valley Formation near the top of the Lower Carboniferous Rundle Group. The reservoirs are located between 5,000 and 6,500 feet (1520 to 1980 m) below sea level and the traps are formed along the eastern edge of west dipping thrust plates. The cumulative production of the Jumping Pound field to January, 1970 was 301 billion cubic

feet of gas and 2.56 million barrels of condensate. In addition, considerable sulfur has been recovered from the H_2S contained in the gas.

To the west the road cuts through ridges of Upper Cretaceous sandstones and shales.

STOP 1-2
44.0 miles
(70 km)

Western Foothills and McConnell Thrust Sheet

To the north, across the Bow River Valley (Fig. 1-1) Mount Yamnuska is composed of Middle Cambrian Eldon Formation carbonate which lies above a flat-lying portion of the McConnell Thrust. Beneath the thrust are Upper Cretaceous Belly River Formation sandstones and shales. The fault trace is readily seen at the heads of some of the small gulleys below the massive limestone cliff. Rocks near the fault are little contorted at this locality. The horizontal displacement is in excess of 5 miles (8 km) and from structural reconstruction, the total displacement is in the order of 25 miles (40 km). The fault is named after R. G. McConnell, who recognized that this structure was a reverse fault when he published the first cross-section of this part of the Rockies in 1886. The McConnell Thrust here forms the boundary between the Front Ranges and the Foothills.

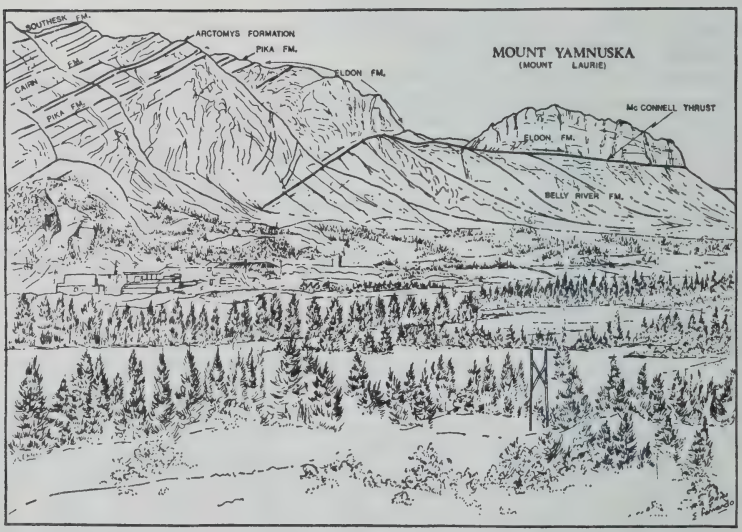

Fig. 1-1. Sketch of the McConnell thrust fault at Mount Yamnuska from the Trans-Canada Highway (R. A. Price with E. Fernando, 1972).

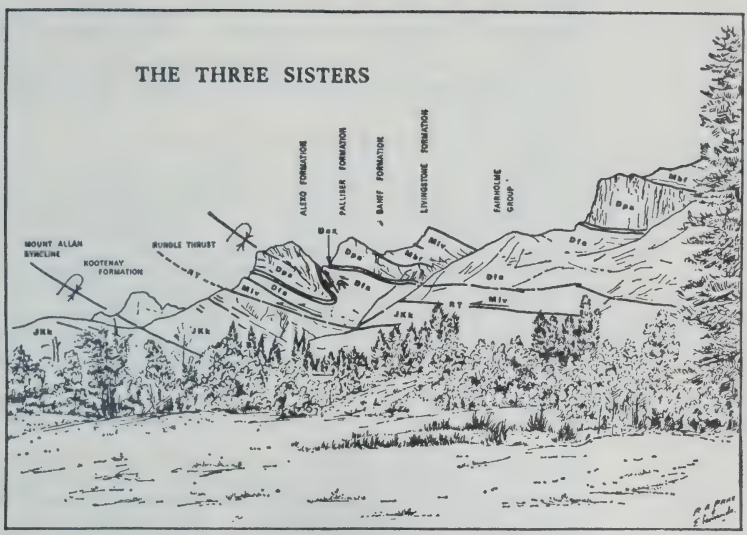

Fig. 1-2. Sketch of the Three Sisters from the Trans Canada Highway near Canmore (R. A. Price with E. Fernando).

To the west, (left) of Mount Yamnuska is a succession of Middle Cambrian, Upper Devonian and Lower Carboniferous strata. The Cambrian-Eldon Formation is highly contorted immediately adjacent to the McConnell Thrust. The Devonian strata are here recognized by their darker weathering colour.

A few miles to the west the Exshaw and Lac des Arcs Thrusts are crossed near Lac des Arcs.

STOP 1-3 *Front Ranges - Fairholme Range and Three Sisters in the Rundle Range*

58.0 miles (92.8 km)

To this point, the route has crossed two main thrust plates involving Paleozoic and some lower Mesozoic strata. The Fairholme Range exposes a sequence of Carboniferous strata of the Banff Formation and Rundle Group (Livingstone and Mount Head Formations). To the west is a third thrust sheet, the Rundle. To the south is a view of the Three Sisters (Fig. 1-2) formed by resistant parts of the Livingstone and Palliser Formations which have been folded and faulted into a recumbent anticline and syncline above the Rundle Thrust. Below the thrust, the Jurassic Kootenay Formation forms the recumbent Mount Allan syncline. These folds are concentric. The syncline forms part of the Cascade-Canmore Coal Basin, the

coal being obtained from the base of the Upper Jurassic Kootenay Formation.

After entering Banff National Park (mile 61.2, km 97.9) the road follows along the strike in Mesozoic strata (not exposed).

STOP 1-4
68.6 miles
(109.8 km)

Rundle Thrust and Strata of Fernie Group

Devonian strata of the Palliser Formation (?) are thrust over overturned strata of the Jurassic Fernie Group on the east. To the northwest in a continuation of the Rundle thrust sheet is a nearly complete sequence of Devonian and Lower Carboniferous strata on Cascade Mountain, which is typical of the central part of the Alberta shelf and this part of the Front Ranges. (Road junction Mount Norquay and Banff Townsite — mile 72.0, km 115.2).

STOP 1-5
73 miles
(116.8 km)

Mount Rundle and Sulphur Mountain near Banff

The homoclinal Rundle and Sulphur Mountain thrust sheets can be observed to the southeast across the Bow Valley, both exposing nearly the same stratigraphic sequences. The Sulphur Mountain Thrust is poorly exposed and occurs in the trees below the lowest outcrops visible on the east side of Sulphur Mountain. Flows of hot mineralized waters are believed to emerge along the trace of the Sulphur Mountain Thrust. The waters appear to be of meteoric origin which acquire heat at depth and either travel upwards along the fault or through porous parts of the Fairholme Group strata. The next thrust sheet to the west, the Bourgeau, can also be seen from this viewpoint. The stratigraphy is essentially similar to what has already been seen east of Banff in the Fairholme and McConnell thrust sheets.

STOP 1-6
76.7 miles
(122.7 km)

Sawback Range

To the north is a good view of the west side of the Sawback Range (Fig. 1-3) a homocline containing Cambrian and Ordovician units which appear in the stratigraphic sequence for the first time beneath a major regional unconformity at the base of Upper Devonian strata. The range is underlain by the Bourgeau Thrust. Some of the formations visible on the skyline cannot be traced to the highway due to cross-faults that intersect the strata of both the Sawback Range and the range immediately to the east. These cross-faults have right lateral offsets, and are associated with the change in stratigraphic position of the Bourgeau Thrust from low in the Middle Cambrian (to the south) to high in the Middle Cambrian (to the north).

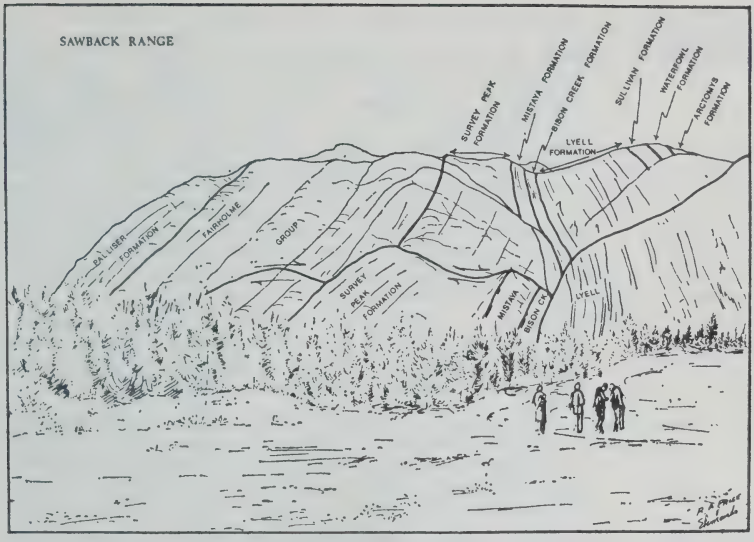

Fig. 1-3. Sketch of the south end of the Sawback Range from Trans Canada Highway (R. A. Price and E. Fernando).

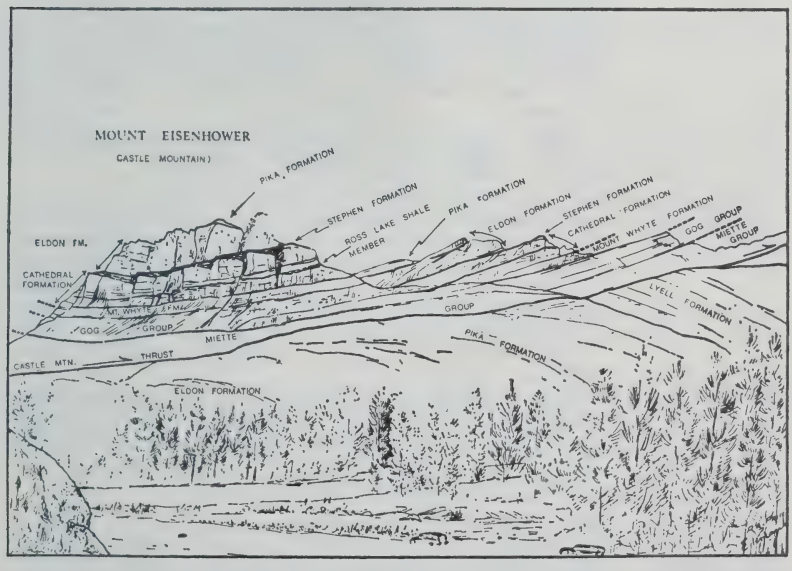

Fig. 1-4. Sketch of Mount Eisenhower from the Trans Canada Highway at Copper Mountain (R. A. Price with E. Fernando).

STOP 1-7
89.0 miles
(142.2 km)

Main Ranges - Mount Eisenhower

The Mount Eisenhower massif (Fig. 1-4) is underlain by the Castle Mountain Thrust. This thrust together with the Johnson Creek Thrust and Simpson Pass Thrust at this point form the eastern boundary of the Main Ranges. The thicker stratigraphic flat-lying succession of Cambrian and Ordovician strata is characteristic of the eastern Main Ranges. Mount Eisenhower, on which is exposed a complete Middle and Lower Cambrian succession and a small part of the underlying late Proterozoic Miette Group, is typical of the Main Ranges.

Beneath this rather simple, relatively undeformed thrust sheet is an extremely complex, steeply dipping, highly deformed sequence of Upper Cambrian and Ordovician strata (Fig. 2).

The highway follows along strike in a glaciated U-shaped valley to Lake Louise. The few outcrops are part of the Miette Group (Windermere) in the hanging wall of the Castle Mountain Thrust. (Mile 109, km 174.4 — Lake Louise road junction).

STOP 1-8
110.0 miles
(176.0 km)

Miette Group Slates at Junction of Banff-Jasper Highway and Trans-Canada Highway

Cleaved dark grey argillites, siltstones and sandstones of the Miette Group illustrate the greater degree of tectonic deformation within these strata in contrast to that of the younger rocks. To the south and west on the mountain slopes across the valley the overlying Gog sandstones are succeeded by a thick sequence of Middle Cambrian carbonates.

The road turns westerly and gradually cuts across stratigraphically higher strata.

STOP 1-9
113.7 miles
(181.9 km)

Outcrops of white and pink quartzite with some argillite beds of the Lower Cambrian Gog Group.

Crossbedding indicates deposition by currents flowing from northeast to southwest. The last outcrops to the east along the highway consist of coarse feldspathic grits of the Miette Group (Windermere). To the west, in the upper part of the Gog, limestone beds contain late Early Cambrian *Olenellus* fragments.

Nearby is the Great Divide and the Alberta-British Columbia boundary at the summit (5339 feet, 1625 m) of the Kicking Horse Pass. The transcontinental railroad reached this point in 1883 and was completed from coast to coast in 1885.

STOP 1-10
118 to
119.6 miles
(188.8 to
191.4 km)

The route has continued up section to the massive carbonates of the Middle Cambrian Eldon Formation. Down the steep hill to the Spiral Tunnels Lookout (mile 119.6) one traverses down section through nearly flat-lying, mainly carbonate strata

of the Middle Cambrian to the Lower Cambrian Gog quartzites. A prominent west-side down normal fault (characteristic of the Main Ranges) can be observed in the mountains nearby.

STOP 1-11
125 miles
(200 km)

Western Main Ranges

The major facies change from the eastern facies (observed in the previous stops) to the western argillaceous facies is well displayed near Field on Mounts Stephen and Dennis across the valley (Fig. 1-5). Well-bedded carbonates on Mount Stephen dip westward. Westward around the cirque, tongues of greenish-grey shale appear and are interbedded with argillaceous carbonate. The Chancellor sequence is divisible into slate and argillaceous limestone units which correlate in a general way with shale and carbonate units in the eastern carbonate facies. These Chancellor units are generally more than twice as thick as their eastern correlatives, but the relative importance of sedimentary thickening versus tectonic thickening has not been determined. The change in structural style which corresponds with this facies change, marks the boundary between the eastern and western Main Ranges.

Road outcrop on the right is Middle Cambrian carbonate transitional to western shale facies with faint cleavage and lineation and calcite veins in cleavage planes.

To the west are road outcrops in well cleaved Middle and Upper Chancellor argillaceous limestones and slates.

STOP 1-12
131.6 miles
(210.6 km)

North end of Mount Goodsir and road cut in Chancellor slate.

Bedding is outlined by layers of elongate limestone nodules, and is folded about northwest-trending axes. Two sets of cleavage are developed; the older set is penetrative and dips moderately to the southwest, and is truncated by a younger, nearly vertical, strain-slip cleavage. Calcite veins in the older cleavage are folded about northwest-trending axes.

To the north across the river is a synclinorium of Chancellor strata with the core outlined by Upper Cambrian Ottertail limestone.

STOP 1-13
138.4 miles
(121.4 km)

Small quarry in overturned Ottertail, partly dolomitized, micritic limestone, with small folds, indistinct cleavage, several sets of fractures, and calcite veins. View east across Kicking Horse Valley illustrates resistant Ottertail limestone forming the main peaks, and less resistant Chancellor slates out-cropping in the lower tree-covered slopes. Dark coloured rocks form the northern part of the Ice River complex, an irregular laccolith-like body embracing a variety of leucocratic to melanocratic alkaline igneous rocks, ranging

from nepheline syenite to jacupirangite (K-Ar ages from 327 to 395 m.y., Rapson, 1963, Early Carboniferous to Devonian).

The next outcrops are largely overturned Cambro-Ordovician, McKay Group (west entrance to Yoho National Park at mile 141.0, km 225.6).

STOP 1-14
146.4 miles
(234.2 km)

Middle part of Kicking Horse Canyon in faulted limestones in uppermost part of McKay Group. The fault (Fig. 1-6) is probably a southwesterly overturned thrust. Beds to the right are in the overturned footwall, and are truncated by beds to the left in the overturned hanging wall. Black shales at the west end of the road cut are Lower to Middle Ordovician Glenogle Formation (zone of *Papaglossograptus etheridgei)* in transitional contact with the McKay Group.

Road outcrops continue in Mount Wilson, Glenogle and McKay strata.

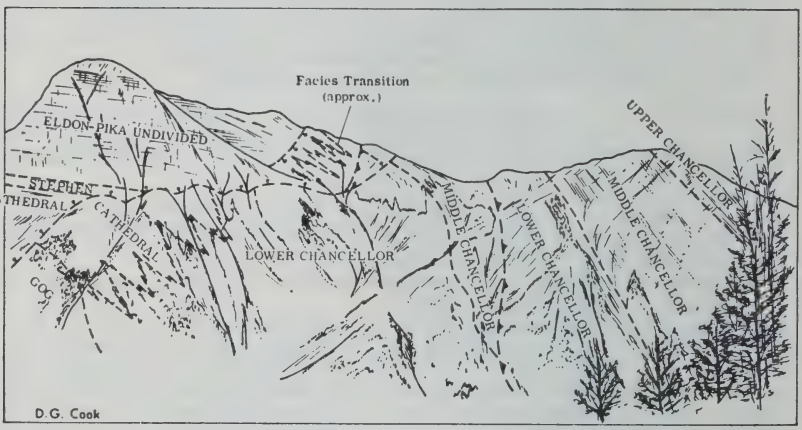

Fig. 1-5. Sketch of zone of facies change between Mount Stephen (left) and Mount Dennis (right) from near town of Field (D. G. Cook).

STOP 1-15
154.2 miles
(246.7 km)

Rocky Mountain Trench

View of Trench from top of hill overlooking Golden. Highly cleaved McKay Group pelites, complexly folded in a synclinorium form the floor of the Trench. In the Dogtooth Range on the west side, the west-dipping Purcell Thrust occurs near the base of the range. Strata in the hanging wall of the thrust are folded and faulted Late Proterozoic (Windermere) and Lower Cambrian quartzites and carbonates with faults and axial planes of folds dipping southwesterly. (Mile 154.7, km 247.5 — Golden and junction with route to Radium Hot Springs.)

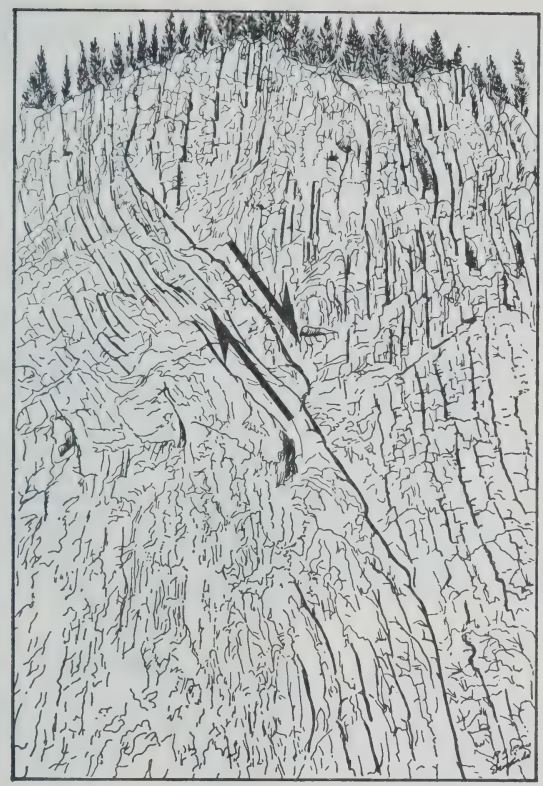

Fig. 1-6. Sketch of overturned thrust fault (contraction fault with normal fault separation) in the upper part of the McKay Group at the upper end of Kicking Horse canyon (R. A. Price with E. Fernando).

Continue to Revelstoke for night. On Day 2 some of the excursion group will fly from Revelstoke to Invermere and return to Revelstoke by surface; some will travel to Invermere by surface and fly back to Revelstoke.

Day 2: Core Zone, Eastern Cordilleran Fold Belt

This segment of the excursion (by helicopter from the Rocky Mountain Trench at Invermere to Revelstoke or vice versa, illustrates the contrasting stratigraphy, structural style, and metamorphic grade of the Upper Precambrian-Paleozoic strata of the Purcell anticlinorium (Stops 2-1 to 2-3) and Kootenay Arc (Stops 2-3 to 2-6). The unconform-

ity between Purcell and Windermere beds (Toby conglomerate) will be examined, as well as the Broadview allochthone and the evidence for pre-Late Mississippian deformation.

A few stops will also be made (by motor vehicle) along the Rocky Mountain Trench from Golden to Radium Junction (Stops 2-7 to 2-9).

Flight Log, Invermere to Revelstoke (Fig. 2)

STOP 2-1
Elev. 8,000 feet (2440 m)

Toby Conglomerate — Mount Brewer, in cirque at head of Brewer Creek, about 12 miles (19 km) southwest of Invermere

Exposure on cirque wall (Fig. 2-1) of about 1600 feet (480 m) of Toby conglomerate lying on Mount Nelson Formation of the Purcell System. This exposure is representative of an extensive regional unconformity between the Purcell-Beltian rocks below, and the latest Precambrian (Windermere) above. The Toby Formation is extremely variable in thickness (up to 2,000 feet, 610 m), in composition of matrix, and in size, shape, and composition of clasts. An origin as a tillite, and as a conglomerate deposited after the Purcell orogenic episode has been considered for the Toby.

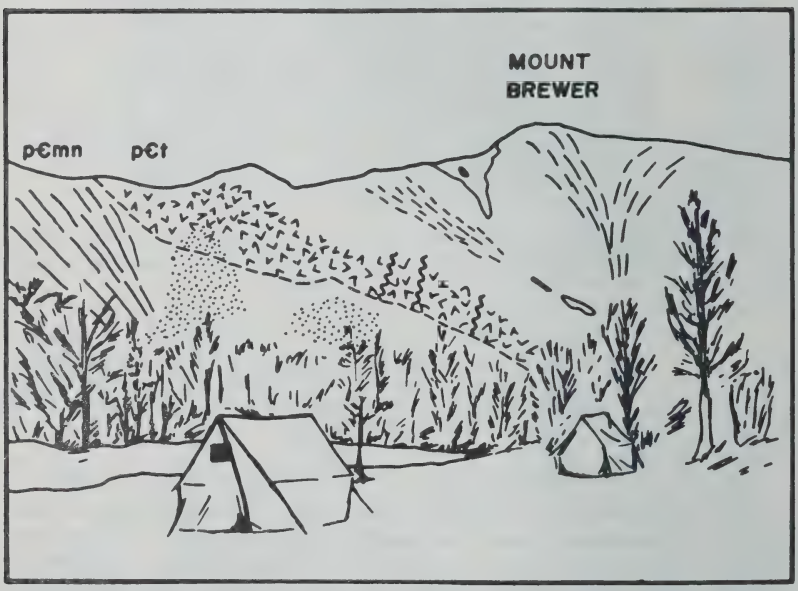

Fig. 2-1. Mount Brewer, showing contact between Toby Formation (pCt) of the Windermere and Mount Nelson Formation (pCmn) of the Purcell. (After photograph by Walker, 1926).

Flight from Stop 2-1 to 2-2 — Infold of Windermere in the Purcell anticlinorium outlined by Toby conglomerate. The syncline has the characteristic shape, with vertical west limb and gently west-dipping east limb, of folds along the east side of anticlinorium.

STOP 2-2 *Cambrian to Devonian section of Mount Forster and Law Ridge.*
Elev. 8,500 feet (2595 m)

The outcrop here is predominantly of Windermere slate. To the north, in infolds on Law Ridge and on Mount Forster, is preserved a complete section of the lower Paleozoic (Fig. 2-2). On Law Ridge about 40 feet (12.2 m) of Lower Cambrian rests on Windermere (Horsethief Creek Group). This is followed abruptly by 400 feet (122 m) of Middle and/or Upper Cambrian Jubilee dolomite, then by about 40 feet (12.2 m) of Ordovician-Silurian Beaverfoot Formation unconformably overlain by Devonian. All the formations below the Devonian thicken rapidly in all directions, and we are standing on an area that remained high, if not emergent, during much of the early Paleozoic. Mount Forster farther northwest (Fig. 2-2) shows a more extensive development of all these formations except the Lower Cambrian, which is absent. The Jubilee Formation (Middle and/or Upper Cambrian) lies directly on Windermere and is about 1300 feet (400 m) thick. Other pre-Devonian formations are correspondingly thicker than on Law Ridge.

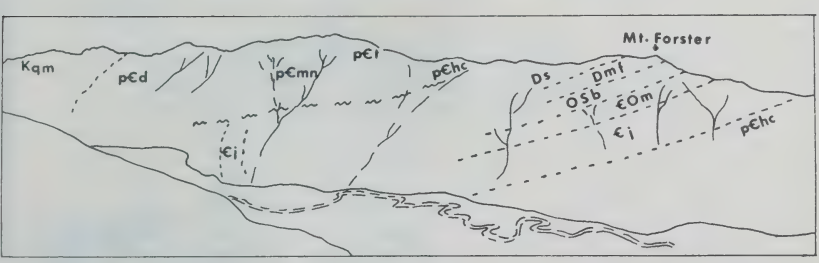

Fig. 2-2. Mount Forster showing lower Paleozoic section and its relation to the Late Precambrian: Kqm-Quartz Monzonite pCd — Dutch Creek Formation; pCmn — Mount Nelson; pCt — Toby Formation; pChc — Horsethief Creek Group; Cj — Jubilee Formation; COm — McKay Group; OSb — Beaverfoot Formation; Dmf — Mount Foster Formation; Ds — Starbird Formation. (Modified after Reesor, 1972.)

Flight from Stop 2-2 to Stop 2-3 — Climb to about elevation 11,000 feet (3355 m) and look northward at the plunging Purcell anticlinorium outlined by Mount Nelson dolomites.

Descend and fly past the southwest shoulder of Mt. Taurus to see Toby conglomerate truncating upper Mount Nelson quartzite, the high peaks on the left

are formed from quartz-monzonite of the Cretaceous Horsethief batholith.

Turn southward in long loop toward Mt. Monica to see about 3,000 feet (915 m) of Lower Cambrian quartzite, which is absent on Mt. Forster less than 20 miles (32 km) to the northeast.

Turn northward and fly over Windermere, Horsethief Creek Group, to Four Squatters Range.

STOP 2-3 *Four Squatters Range. Horsethief Creek Group (Windermere) phyllites*

Elev. 8,000 feet (2440 m)

There is a notable contrast in metamorphic grade between the last landing (stop 2-2) and this locality. The metamorphism in the Lardeau area increases progressively from the slate belt in the northeast to staurolite-kyanite schist in the southwest accompanied by a dramatic change in fold style between the lower Paleozoic strata of the Brisco Range to the northeast and the Kootenay arc to the southwest (Fig. 2-3). Some of the complex folds are illustrated at the next stop to the northwest in the Selkirk Mountains (Fig. 2-4).

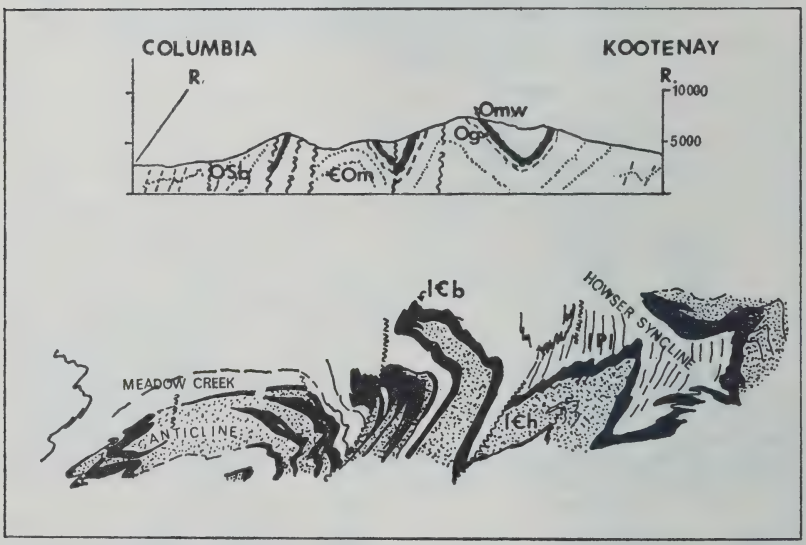

Fig. 2-3. Structural contrast between lower Paleozoic rocks of Brisco Range in Rocky Mountains and Kootenay Arc in western Purcell Mountains: COm — McKay; Og — Glenogle; Omw — Mount Wilson; OSb — Beaverfoot; lCh — Hamill; lCb — Badshot; lPl — Lardeau. (Upper fig. from Reesor, 1972; lower fig. from Fyles, 1964: both figures approximately 10 miles, 16 km across).

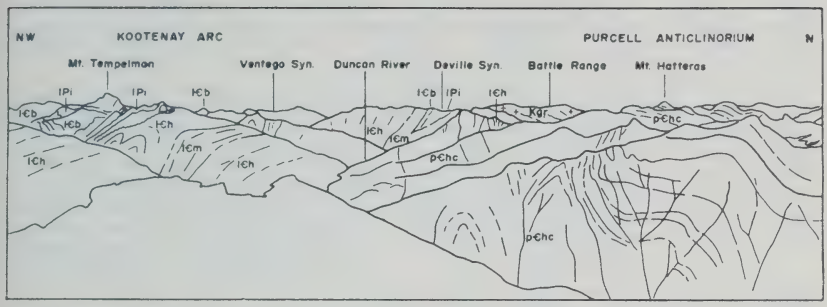

Fig. 2-4. View north and northwestward from the Four Squatters Range. Showing the transition from mainly broad, open folds in the Windermere of Purcell Anticlinorium to the tight relatively upright folds of the Lower Paleozoic rocks of Kootenay Arc west of Duncan River. Legend as in Fig. 2-5 (J. O. Wheeler).

Flight from Stop 2-3 to Stop 2-4 — Fly southwestward across the valley of Duncan River (Purcell Trench) and up Hall Creek. Lower Cambrian quartzite (Hamill Group) underlies the lower slopes of the eastern valley wall and most of the western valley wall, where a narrow upright syncline of Lower Cambrian phyllite and limestone (Mohican Formation) is present.

Continue to the head of Hall Creek where lower Paleozoic black phyllites of the Index Formation (Lardeau Group) outline two tight synclines within the Lower Cambrian Badshot limestone. The east limb of the easterly syncline is faulted bringing the Index phyllites against the upper part of the Lower Cambrian quartzite. The westerly syncline passes west of the summit of Mount Templeman. The two synclines are separated by an anticline which, in the transverse valleys of Hall and Stevens Creeks, exposes the upper part of the Lower Cambrian quartzite.

Fly northwesterly past the east side of Mount Templeman and bear northwesterly across the head of Stevens Creek to Lade Peak. There is an excellent view of nearly vertical Badshot limestone known by the old prospectors as the Lime Dyke, composed of a tight, isoclinal anticline-syncline pair.

STOP 2-4 *Lade Peak*
Elev. 8,100 feet
(2470 m)

Outcrops of quartz-phyllite and limestone of the lower Paleozoic Index Formation. Extensive parts of the ridges to the north and northwest (Fig. 2-5) are underlain by black, buff, and green phyllites and subordinate limestone and greenstone of the Index Formation. Figure 2-5 shows the charac-

teristic fold style — attenuated similar folds having N-shaped profiles when looking north as they climb upward to the east onto the western limb of the Purcell anticlinorium.

In the distance, to the northwest, are exposed higher lower Paleozoic units — black siliceous phyllite of the Triune and Sharon Creek Formations which are separated by an excellent horizon-marker, the Ajax quartzite. Lying farther west, above the Sharon Creek Formation, is the Jowett Formation composed of altered basic lavas, locally pillowed, and minor pyroclastics. It underlies the high peak of Spine Mountain and Mounts Jowett and Pool.

The mountain west of Mount Pool is underlain by the allochthonous Broadview Formation — probably a westerly facies of the Windermere Horsethief Creek Group.

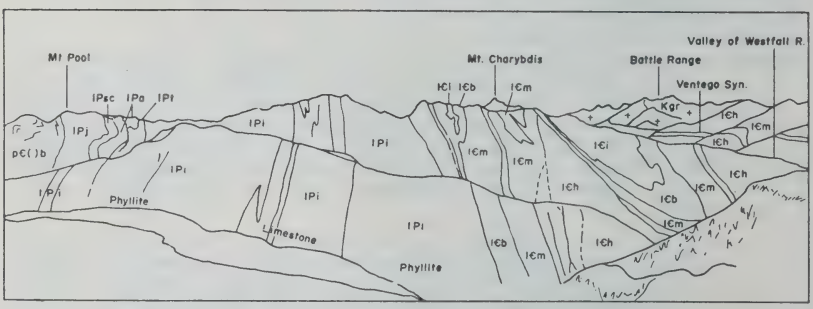

Fig. 2-5. View north from Lade Peak showing the tight, upright N-shaped folds climbing eastward in the Lower Paleozoic rocks of Kootenay Arc. These structures are redeformed locally as in the Ajax Quartzite and adjacent units near Mount Pool by reverse N-shaped folds and westward overriding reverse faults. Ventego syncline in distance at right in front of Battle batholith. Legend: pChc — Horsethief Creek, 1Ch — Hamill; 1Cm — Mohican; 1Cb — Badshot; 1Pi — Index; 1Pt — Triune; 1Pa — Ajax; 1Psc — Sharon Creek; 1Pj — Jowett; pC(?)b — Broadview; Kgr — granitic rocks (J. O. Wheeler).

Flight from Stop 2-4 to Stop 2-5 — Proceed westward across the head of Surprise Creek and down Ferguson Creek. The ridge to the south (left), east of Spine Mountain and the one to the northwest, east of Mount Pool, are underlain by the white Ajax quartzite between siliceous black phyllites. These units display steep, northeast-dipping reverse faults and associated folds with reverse-N profiles (Phase 3) when looking north. The faults and folds are later than the N-shaped (Phase 2) and were developed during the late backfolding phase (Phase 3) in the Kootenay Arc.

Fly westward across Ferguson Creek valley south of Mount Pool where green outcrops occur of the altered basic volcanics of the Jowett Formation. The fault-contact between the Jowett and Broadview Formation (i.e. the base of the Broadview allochthone) is nearly vertical and intersects the ridge just east of the saddle west of Mount Pool. Note the step-like 2nd phase folds in the Broadview on the mountain face west of the saddle. These folds, like the attenuated N-shaped folds seen from Lade Peak (Stop 2-4), climb eastward, but contain mesoscopic 1st phase isoclines.

Continue westward across the terrain underlain by the Broadview Formation — mainly phyllitic quartzo-feldspathic grit, sandstone, and phyllite. Huge blocks of phyllitic sandstone, ranging up to several hundred feet across, lie "floating" in highly contorted phyllites southeast of Mount Thompson. The region around Mount Thompson occupies a structural depression in the Broadview allochthone. To the southeast the 2nd phase folds plunge 10° to 20° to the northwest whereas to the northwest they plunge 10° to 30° southeast off the Clachnacudainn salient of the Shuswap complex.

STOP 2-5
Elev. 6,650 feet (2030 m)

1.5 miles (2.4 km) southwest of Mount Thompson

Slopes northeast of the landing meadow are underlain by phyllitic grit and sandstone containing a steeply northeast-dipping bed of buff dolomite and grey marble associated with maroon and green slate — all belonging to the Broadview Formation.

The timbered ridge southwest of the meadow comprises Broadview phyllitic grit and sandstone apparently underlain by conglomerate that forms the crest of the ridge and the cliffs below it to the southwest. The conglomerate, however, is composed of clasts up to 14 inches (35 cm) across of phyllitic sandstone, greenstone, and greenish and greyish slate, all of which are typical of the Broadview Formation, lying in a reddish phyllitic matrix. Furthermore, the Broadview clasts display a foliation that is randomly oriented, indicating that the Broadview Formation had undergone penetrative deformation before being incorporated into the conglomerate. The conglomerate unconformably overlies the Broadview Formation and the section is overturned to the southwest, a typical feature of the backfolding in the Kootenay Arc.

Limestone, about 150 feet (45 m) down the slope, contains Upper Mississippian corals. Thus the conglomerate represents the base of the Permo-Carboniferous Milford Group and indicates that the Broadview Formation was deformed prior to Late Mississippian.

Flight from Stop 2-5 to Stop 2-6 — Proceed northwest across the northeast arm of Upper Arrow Lake. Sproat Mountain north of the arm is underlain by phyllite, quartzite, and limestone of the Milford Group. The limestone is clearly visible on the mountain north of Sproat Mountain. The Broadview Formation underlies the ridges to the northeast, culminating in Comaplex Mountain, from which a belt of greenstone extends northwestward displaying characteristic greenish outcrops.

The Akolkolex River valley exposes lower Paleozoic — particularly Cambrian — phyllite, quartzite, and limestone in southeast-plunging structures lying beneath Windermere strata of the Broadview allochthone.

STOP 2-6
Elev. 6,200 feet (1890 m)

About 2 miles (3 km) northwest of the junction of the northeast and southeast forks of the Akolkolex River

The stop is on the Lower Cambrian Badshot limestone, whlch here contains archeocyathids, forming the upper or south limb of the refolded isoclinal Akolkolex anticline closing to the east. The Hamill quartzite and Mohican phyllite occupy most of the valley to the north, the limestone on the peaks to the north — opposite — belongs to the Badshot Formation on the northern or under limb of the fold. The intricate display of limestone beds sloping to the southeast on the west face of the mountain to the north-east are close to the nose of this southeast-plunging anticline, which is refolded by upright folds also trending southeast. Black phyllite of the lower Paleozoic Index Formation underlies the ridge above and to the south of the stop. It envelops the Badshot Limestone around the nose of the anticline to the east.

Flight from Stop 2-6 to Revelstoke — Proceed northward past the peaks opposite and around a prominent mountain a mile or so farther north underlain by much limestone. This peak is composed of interdigitating Index phyllite, Badshot limestone and Mohican phyllite forming recumbent folds that verge and climb eastward and represent minor folds on the underlimb of the Akolkolex anticline just east of its nose.

Fly northwest across tightly folded limestone and phyllite of the Badshot and Mohican Formations and over the underlying quartzose sediments of the Lower Cambrian Hamill Group. The siliceous sediments become more highly metamorphosed northward and downward as they pass rapidly and transitionally into the Clachnacudainn salient of the Shuswap Metamorphic complex. The lower slopes are underlain by mapable units of granitoid gneiss typical of those in

the core of the gneiss domes farther west in the complex.

Fly down the Illecillewaet Valley through the Shuswap complex, across the Columbia River to Okanagan Heliport at the entrance of Eagle Pass.

Golden to Radium Along The Rocky Mountain Trench

0.0	Golden — Bridge over Kicking Horse River.
STOP 2-7	*Mitchell Road*
11.1 miles (17.8 km)	Turn off to left for off-highway stop. Good view of Columbia River Valley and Dogtooth Mountains. Excellent exposure of incompetent McKay Group of Cambro-Ordovician age into which the valley is cut.
STOP 2-8 33.0 miles (52.8) km)	*Curve in Road* Just opposite Jubilee Mountain, south of Parson. View toward Hatch Creek best in late afternoon. Tight upright fold typical of Brisco Range to the east, outlined by contrasting lithologies of Mount Wilson Quartzite (Ordovician), Beaverfoot (Ordovician and Silurian) and Devonian (Cedared and Harrogate Formations).
STOP 2-9 39.5 miles (63.2 km)	*Spillimacheen* Jubilee and Steamboat Mountains in Rocky Mountain Trench, both carved in synclines, typical of the east side of the Purcell Mountains, with steep west limb and gentle west dipping east limb. The Purcell Thrust is located at the base of the east slope of Jubilee and Steamboat Mountains. The north end of the syncline on Steamboat Mountain is deformed and cut by the Mount Forster-Steamboat Thrust that brings the Mount Nelson Formation of the Purcell System against the Beaverfoot Formation (Ordovician-Silurian) in the core of the Steamboat syncline. Mt. Ethelbert and Mt. Horeb, to the west, are formed of Mount Nelson Formation on the crest of the Purcell anticlinorium. To the east the Mount Wilson and Beaverfoot Formations and McKay Group are exposed in the Brisco Range.
64.6 miles (103.4 km)	Radium Junction

Day 3: The Shuswap Metamorphic Complex

Introduction

This segment of the excursion displays the inner, high-grade metamorphic axial zone of the eastern fold belt — the structural style, migmatization and upper amphibolite meta-

morphism, of strata ranging in age from late Precambrian to early Mesozoic (Fig. 2).

The Shuswap Metamorphic complex underlies more than 20,000 km^2 in the axial zone of the Eastern Fold Belt. Most of the Shuswap complex is of the upper amphibolite facies of regional metamorphism and much of it is characterized by extensive concordant to semi-concordant pegmatite. Local metamorphic highs in the sillimanite-potassium feldspar zone correspond approximately with domal culminations (Fig. 2).

The strata of the complex range in age from late Precambrian to early Mesozoic. Quartzite, marble, calcium silicate gneiss and pelitic schist within the Shuswap complex are considered to be the equivalent of the Lower Cambrian of the Selkirk and Purcell Mountains to the east. Higher in the section carbonate, quartzite and marble are considered correlatives of the Mississippian to Permian Milford Group.

The dominant early structures on all scales in the Shuswap complex trend east-west. Large scale, isoclinal, recumbent, northward-verging folds are the earliest structures recognized, and at least two later sets of structures trending generally northerly to northwesterly are superimposed on them.

The eastern part of the Shuswap complex is characterized by a number of large domal structures developed at intervals of about 50 miles (80 km). Although each dome exhibits individual variations, each is characterized by core zones of migmatite and granitoid gneiss enveloped by mantling gneiss of the heterogenous quartzite, marble, schist sequence. Thus the Valhalla dome consists of an extensive tongue of orthogneiss, which has been displaced eastward over about 11 miles (18 km), within an envelope of migmatized metasediments. The Thor-Odin and Frenchman's Cap domes appear to be rooted in situ and the principal movement in their core zones has been vertical. The Pinnacle Peaks dome is not eroded as deeply as the other domes and there a large north-verging isoclinal fold in varied metasediments marks the culmination of the dome in contrast to the typical gneiss cores of the larger domes. In the Pinnacle Peaks dome there is preserved in places the rapid transition to the rocks of the supracrustal zone, from the sillimanite grade of metamorphism to the greenschist facies over a distance of a little more than a kilometer. Just as in the local metamorphic high in the Kootenay Arc to the east, here also the isograds

Table 3-1. Structural-lithological units and sequence of structural and metamorphic events, Thor-Odin gneiss dome.

Subdivision	Lithology	Structural episodes and metamorphism		
		F_1	F_2	F_3
Supracrustal Zone	Andesitic metavolcanic rocks; quartz-sericite schist; phyllite, quartzite, marble; granitic rocks intrusive veinlets and small stocks.	Isoclinal folding with development of strong axial-plane foliation. Fold directions vary. Metamorphism up to staurolite-almandine subfacies.	Marked by strong cleavage cutting earlier-formed garnet. Mica strongly recrystallized along cleavage planes.	Brittle fracture along cataclasite zone with associated retrograde metamorphism. Some large-scale folds, north-trending, that affect all earlier structures. Waning metamorphism, but some evidence of post-F_2 recrystallization.
Fringe Zone	Similar to mantling zone, below, with dominant pegmatite and granitoid rock in conformable to semi-conformable layers.	Northward verging, east-west oriented folds with amplitudes up to several thousand feet. Westward and upward in the structural-lithological succession these folds become more open and disappear. Most of the Fringe-Mantling zones in sillimanite-almandine-orthoclase subfacies. Outer periphery of sillimanite-almandine-muscovite subfacies.	Late F_2 sillimanite lineation in some localities with west southwest orientation. Progressive modification of earlier folds near core zone. General large-scale uprise along northerly trending axis along entire eastern limit of metamorphic complex. Coincident development of strong streaking lineation in pegmatite and granitoid layers emplaced synchronous with F_1 movement phase. Metamorphism continued at highest level and recrystallization kept pace with movement.	Some small-scale crenulations, open folds and warps, not penetrative. Trend northwest to northerly with vertical axial planes. No synchronous recrystallization as in previous episodes. Minor retrograde metamorphism along northerly-trending bleached fractures.
Mantling Zone	Quartzite, pelitic schist, marble, calc-silicate gneiss conformable to cross-cutting pegmatite and granite.			
Core Zone	Biotite-quartz-feldspar gneiss in some cases with dominant quartz. Well-layered with biotite-rich, vs quartz-feldspar-rich layers; veined - hornblende - biotite granodiorite gneiss. Much granite and pegmatite.	Interfolding of core-zone migmatites and mantling zone cover with amplitude up to several thousand feet. Configuration and direction of folds reflects mobility of core zone and fold axes trend from west to northerly. Metamorphism in sillimanite-almandine-orthoclase subfacies.	Intense development of flexural-flow folds with curvilinear axes trending generally northwest to northerly. Synchronous development of a strong lineation normal to trend of these fold axes. Refolding of earlier large folds. Small folds at this stage reflect diapiric movement of core zone and are parasitic on the core as a whole not on individual large folds. Metamorphism continued at highest level.	Sporadic folding and warping, commonly on vertical axial planes. In western core zone strong recrystallization followed cessation of all penetrative movement.

are very steep on the outer limit of the Shuswap complex. By contrast, in the interior zone of the high grade metamorphic zone the isograds exhibit a gently undulating, flat-lying upper surface. The character of the isograds here and in the Kootenay Arc taken together with the similar stratigraphic section in the Shuswap complex and in the Selkirk Mountains leads to the conclusion that metamorphism within the Shuswap complex resulted from high heat rise along a relatively narrow linear belt within the core of the Eastern Fold Belt rather than extensive downfolding and deep burial.

All of these features cannot be examined in a single day even by helicopter, and the field trip will concentrate on the core and mantling zones of the Thor-Odin gneiss dome (Reesor and Moore, 1971).

Thor-Odin Gneiss Dome

The accompanying Table 3-1 outlines the lithological units and structural features of the Thor-Odin gneiss dome (Reesor, 1970, p. 76). Marble and calcium silicate gneisses are rare in the core zone whereas they characterize the mantling zone. The mantling gneisses are separated from the core zone not only on the basis of lithological contrasts, but also on the extent and character of migmatization, on structural style, and by their rusty weathering characteristic.

Some of the core gneisses may have been derived from the succession of pelitic schists and quartzitic gneisses now found southwest of the core zone between core gneisses and the quartzite-marble schist successions. Within the large infolds of mantling gneiss in the core zone it is the quartzite-marble-calc-silicate succession that lies directly on the core gneisses.

"There is no recognizable unconformity between the quartzite-calc-silicate-schist succession and the underlying metasediments. Migmatization post-dates the deposition of these strata, for in zones of intense deformation layered gneisses similar to core gneisses may be developed in pelitic layers above the quartzite. There is no evidence of a group of metasediments lying unconformably upon an older gneissic terrain.

The Fringe zone, though containing many rock units similar to those in the Mantling zone, is characterized by extensive pegmatitic and granitoid masses. In much of the Fringe zone, pegmatite engulfs the metasediments and stratigraphic continuity is difficult to establish. This zone, on the periphery of Thor-Odin gneiss complex, is typical of the

exposures of much of the Shuswap to the west of the major gneiss domes." (Reesor 1970, p. 77).

The principle structures found in the Thor-Odin gneiss dome have been summarized by Reesor (1970, pp. 77-82).

The Core Zone

The structural culmination of the Thor-Odin gneiss dome lies between Mount Thor and Mount Odin. Layering there is nearly horizontal, but on the flanks dips gently to steeply outward. The domal structure is further shown by the mantling gneisses that encircle the core zone.

Each major structural-lithological unit of the domal complex exhibits a characteristic structural style. Within the core zone, major structures are defined by the infolds of mantling gneiss. The most important of these structures is the Pingston fold, an antiformal syncline draped about the eastern slopes of the domal culmination. The salient features of this fold are summarized as follows:

1. It is outlined by a white quartzite, succeeded by schist and calc-silicate similar to that of the upper part of the mantling zone. It is everywhere enveloped by migmatitic gneisses of the core zone.

2. It is isoclinal with a rounded hinge zone and foliation is parallel with compositional layering.

3. Small-scale folds show relative movement of lower layers upward on both isoclinal limbs of the fold. Their axes trend parallel with the strike of strata.

4. Although present, small-scale structures, apparently parasitic to the major fold, are rarely found in the upper limb. In one or two examples they are refolded by the folds noted in '3' above.

The Pingston fold therefore shows interfolding on a large scale of mantling zone gneisses and core migmatites. This was followed by penetrative movement with the development of small-scale folds. Most such small-scale structures have therefore developed independently of the major fold.

Other infolds of the same mantling strata are found, concordant with the periphery of the core around its southern and western part. The western infolds consist of upright, isoclinal, northerly trending folds outlined by the quartzite member, basal to a succession of schist, calc-silicate gneiss, and marble. The salient features of these folds are:

a) The western infolds appear to be very narrow keels of synclines, with northerly trending axes as shown by the continuity of stratigraphic layering and by smaller scale folds of outcrop size.

b) Infolds show refolding on a smaller scale with axes plunging down the dip of the strata. Thus in the southern infold, fold axes plunge southerly and in the western infold, southwesterly. These small-scale folds are cylindrical and are characterized by strong mineral rodding and lineation parallel with fold axes.

c) Second-stage folds are in turn, in the western infold, refolded by later open warps with northwesterly trending axes.

Within the dominant gneisses and migmatites of the core zone the style of folding is featured by ubiquitous small-scale folds with curving axes and a strong streaking lineation nearly normal to the trend of the axes. Some features of the core folds are as follows:

a) Folds are of flexural-flow type, with strongly curving axes, commonly up to 90 degrees within a few feet.

b) Folds develop en echelon; adjacent folds may show an axial depression in one, beside an axial culmination of the other. Therefore the curving form of the axes is not due to crossfolding at a high angle.

c) Cleavage is not commonly developed parallel with axial surfaces, though schistose layers concentrated in axial zones may show a crenulation foliation. Lineation parallel with fold axes is confined to the axes of such crenulations or to rare sillimanite needles. Most lineations consist of a streaking or sillimanite-needle lineation nearly normal to the axis of the fold, that is not developed in hinge zones. Regionally it changes direction as the trend of small fold axes change.

d) The style of the folds varies locally from open to tight and the folds are commonly disharmonious, particularly where layering varies greatly in thickness. Fold shape is thus governed by differences in ductility between adjoining layers.

e) Regionally, fold axes trend northerly, changing direction as they are followed around the domal culmination.

f) They clearly refold an established foliation marked by strong concentration of quartzo-feldspathic vs. biolite-rich

layers. However, large-scale earlier folds are not easily recognized within the core gneisses where distinctive markers are absent. Large-scale folds are inferred from the presence of mappable, distinctive lenses of gneiss that occur on a scale similar to that of the mantling gneiss infolds.

The first recognizable event in the structural development of the core zone of the Thor-Odin gneiss dome has been interfolding of core-zone gneisses and overlying mantling gneisses on a scale of thousands of feet. This has taken place at a high grade of metamorphism accompanied by migmatization. Earlier bedding has been emphasized by concentrations of concordant quartzo-feldspathic material and an over-all mobility is attested by the eastward movement of a migmatite tongue above what is now the Pingston fold (Reesor and Moore, op. cit.).

The second stage of movement is characterized by an extensive formation of small-scale folds, that are imposed on the core zone as a whole and are independent of the earlier large scale folds. These structures reflect movement of the core zone as a unit several miles in extent, rather than on a scale of thousands of feet as in the first stage of interfolding of core and mantling zone. Movement at this stage resulted from progressive increase in mobility of the core as a whole to the point at which it moved as a diapiric unit relative to the mantling gneisses. Upward movement of the core zone is attested not only by the present orientation of the Pingston fold, but by the orientation and development of the small-scale folds throughout the core. Core-zone rocks lie well above the gneisses of the Mantling zone in peaks such as Mounts Thor and Odin within the culmination of the dome.

Recrystallization persisted beyond the last movement phase within the core zone. Locally, disoriented sillimanite aggregates up to ¼ inch by 2 inches (6 mm by 5 cm) or more in length are overgrown by cordierite. These minerals have not been affected by later movements.

The Mantling Zone

The most important structures within the metasedimentary gneisses enveloping the core zone consist of north-verging folds with east-west trending axes. Folds of similar shape and vergence occur north of the Thor-Odin core zone (Craig, 1966) as well as in Frenchman's Cap (Wheeler, 1965), southward in the Pinnacle Peaks dome (Reesor and Froese, 1968), and in the Grand Forks Group near Christina

Lake (Preto, 1967, Figure 1). It is clear, therefore, that these early folds have a consistent regional orientation independent of the present configuration of the major domal complexes. Nevertheless the structural evolution within the core zone of the Thor-Odin has had a considerable effect on the structure of the nearby mantling zone, and the important structural features of this zone are summarized as follows:

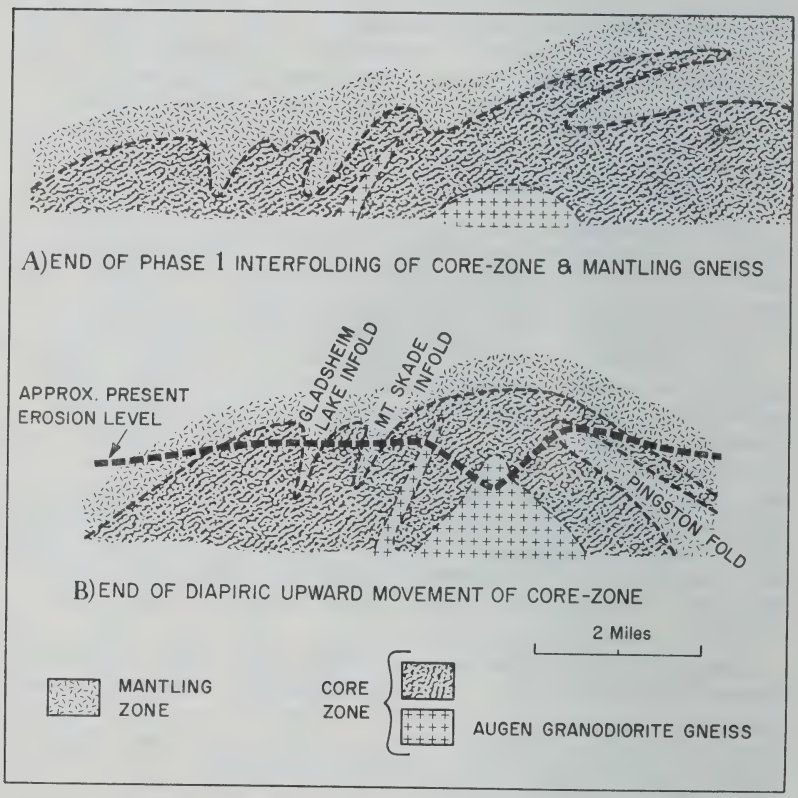
A) END OF PHASE 1 INTERFOLDING OF CORE-ZONE & MANTLING GNEISS
APPROX. PRESENT EROSION LEVEL
GLADSHEIM LAKE INFOLD
MT. SKADE INFOLD
PINGSTON FOLD
B) END OF DIAPIRIC UPWARD MOVEMENT OF CORE-ZONE
2 Miles
MANTLING ZONE
CORE ZONE
AUGEN GRANODIORITE GNEISS

Fig. 3-1. Diagrammatic portrayal of the development of core zone, Thor-Odin gneiss dome. Both sections east-west (from Fig. 17, Reesor & Moore, 1971).

a) Large-scale folds are outlined by marble units southeast and east of Mount Fosthall. Though folds of this type are isoclinal and compressed near the core zone, farther away they are northward-verging; axes trend generally east-west.

b) Near the core zone, antiformal closures cannot be found and are presumed to be sheared out.

c) Small-scale folds are cylindrical with intense mineral rodding and sillimanite lineation parallel with fold axes.

d) Strong lineation and local small-scale folding southwest of the core zone trends southwest; immediately south of the core all structures trend west and strata adjacent to the core are tectonically thinned.

e) In some localities in and near the Fosthall fold (located east-southeast of Mount Fosthall and outlined by the large marble unit, south of the core zone) small folds show relative upward movement of upper beds along the south limb (i.e., opposite to that expected in the syncline). Further, the steep south limb of the Fosthall fold, south of the core, shows a strong refolding on a small scale, though the enveloping surface remains vertical. Recrystallization in the sillimanite-almandine-orthoclase subfacies persisted throughout this phase of folding.

f) Adjacent to the core the effects of late movements in the core zone are clearly evident. Strata are lenticular, and curving shear surfaces are characteristic of the schists. Small-scale folds either have not formed extensively or have been destroyed. Here also, as in the core zone, recrystallization has outlasted all structural disruption and coarse, unoriented sillimanite has grown in the pelitic schists. However, only in one locality within a few feet of the core have cordierite overgrowths been found.

g) Later, more northwesterly trending open folding and warping affected the earlier structures. These features are particularly evident in the zone southwest of the core, but immediately south of the core late features are confined to north-trending warps and open folds. They were developed during a period of waning metamorphism and are sporadic in their distribution.

The Fringe Zone

The Fringe zone, surrounding and transgressing the mantling zone, is characterized by extensive, nearly concordant masses of pegmatite and granitoid rocks. The lack of stratigraphic continuity inhibits easy recognition of large-scale structures. However, clear structural patterns are evident within the zone:

a) Pegmatitic rocks engulf strata folded on east-west axes;

b) Pegmatitic and granitic rocks show strongly lineated biotite-rich segregations or faint grooving and crenulation on some surfaces;

c) To the east, toward the cataclasite zone separating the gneiss complex and the cover rocks, the intensity of the streaking lineation gradually increases, and both quartz and feldspar aggregates are flattened and elongate. Recrystallization has kept pace with deformation and brittle fracture is not evident in much of the area affected. In and near this zone later brecciation is evident, indicating that on the periphery of the crystalline complex the deformation has outlasted recrystallization. This brecciation is related to dome formation, for the zone of disruption dies out southward from the Thor-Odin dome, and, in the Pinnacles area, strata may be traced across it (Reesor and Froese, 1968). Furthermore, the intensity and extent of brecciation and the resultant retrograde metamorphism is greatest close to the Thor-Odin culmination (Reesor and Moore, op. cit. Fig. 8).

Summary

Some features of the Thor-Odin gneiss dome should be emphasized. First, migmatization post-dated the deposition of the quartzite-calc-silicate-marble-schist sequences. Second, intense metamorphism and migmatization began at this early stage, and the orientation of large folds in the core zone reflected and depended upon the configuration of the confining space. Third, diapiric movement of the core modified earlier structures within both the core and the mantling gneisses. This phase of movement corresponded with maximum intensity of structural disruption and greatest extent of metamorphism in the gneiss dome. Fourth, the final stage of movement within the gneisses is recorded by northerly trending, sporadically distributed open warps and folds.

Movements within the Thor-Odin gneiss complex were built successively upon earlier stages. Each stage was dependent to some extent upon both metamorphic and structural developments in earlier episodes. Thus movement progressed from interfolding of core and mantle on a scale of thousands of feet, to diapiric movement of a large unit on a scale of miles (the core zone as a whole), recorded by an intense development of small scale folds. Thermal activity outlasted structural movements in parts of the gneiss complex. Along the eastern periphery of the dome, the latest movement was concentrated along a narrow zone and outlasted metamorphic recrystallization. This final structural

episode recorded movement of a crystalline mass many miles in extent.

Flight Log, Thor-Odin Gneiss Dome

Revelstoke to Stop 3-1 — Start at Revelstoke, climb to about 7,500 feet (2300 m) and fly southward along the eastern side of the Monashee Mountains. Note the dominant mantling gneiss, with massive Lower Cambrian quartzite of Mounts MacPherson and Begbie. The first exposure of core gneiss can be noted just south of the next ridge south of Mount Begbie. Note contrasting colors of the grey to white core gneisses and the rusty metasedimentary mantling gneisses. Cranberry Mountain is carved in core gneiss but note the mantling gneiss immediately west and a lenticular remnant of marble and schist east of the mountain peak. Mount Hall to the east is made up entirely of mantling gneiss. The serrate ridges to the south including both Mounts Thor and Odin are carved from the core gneiss of the Thor-Odin gneiss dome.

The aircraft will circle part of the northeast ridge of Mount Thor. An antiformal syncline (Pingston fold) of metasedimentary mantling gneisses is surrounded by the core gneiss forming the higher peaks. Note the cascading folds in the overlying core gneisses above the quartzite. They are outlined by amphibolites in the migmatites and gneisses of the core.

STOP 3-1
Elev. 7,500 feet
(2,300 m)

Pingston fold, southeast shoulder of Mount Thor.

Pingston fold is outlined by quartzite with the inner members consisting of calcium-silicate gneiss, pelitic schist, and biotite-quartz-plagioclase paragneiss. It is considered to be an early syncline of metasedimentary gneisses reversed into an antiformal position around the eastern periphery of the domal culmination. Cascading folds with axial surfaces dipping towards the domal culmination lower the quartzite on the upper limb of the fold from nearly 9,000 feet (2745 m) on Mount Thor to 4,000 feet (1220 m) in Pingston Creek in about 2 miles (3 km).

Pelitic schists here contain apparently coexisting sillimanite, kyanite, and andalusite. This locality is just on the boundary of the sillimanite-muscovite and sillimanite-potassium feldspar zones.

STOP 3-2
Elev. 7,500 feet
(2,300 m)

Toe of Burnham Glacier

A variety of core gneisses are exposed at this locality. At the stop, augen hornblende-biotite geniss is exposed and just above to the west are layered gneiss and migmatitic gneisses derived from metasediments. The latter show excellent differentiation into quartz-feldspar layers alternat-

ing with biotite- (and sillimanite) rich layers. Folds are typical of the second stage of deformation related to the diapiric rise of the core zone. They are characterized by sharply curving axes and on flat surfaces show typical oval shapes and en echelon development

Flight between *Stops 3-2 and 3-3* — Fly up Odin Creek at about 7,500 feet (2,300 m) to the head of Odin Glacier. On the right is Thor Ridge and on the left Mount Odin. Note that layering steepens to vertical in the western part of the core zone before the next landing.

STOP 3-3 *Core gneisses and Mount Skade infold*

Elev. 7,000 feet (2,135 m)

Irregular migmatitic gneisses in which quartzofeldspathic rock predominates, 'wispy' biotite granitic gneiss, layered gneiss, sillimanite-bearing gneiss with overgrowths of cordierite and many other varieties of rock in the core zone are crossed in this traverse. The Mount Skade infold begins with quartzite, continues in calcium silicate gneiss, and is centred with coarse pelitic gneiss.

The axial surface of this synclinal infold dips steeply westward. This infold can be followed northward into the Blanket Mountain area 25 miles (40 km) away. Traverse down to the south to look at 2nd phase folds plunging down to the west (reclined folds).

Flight between *Stops 3-3 and 3-4* — Note large reclined folds at west end of the Ledge Creek infold. Note also the steep escarpments to the south and west marking the beginning of the mantling gneisses.

STOP 3-4 *Cariboo Alp*

Elev. 7,500 feet (2,300 m)

Land on rusty schists and gneisses of the inner mantling zone. Note zone of intense development of reclined folds, and to the southwest quartzitic paragneisses and platey gneisses characterized by knots and lenses of garnetiferous amphibolite. It is considered that the core gneisses have been derived in part from migmatization of these rocks in a zone of great structural mobility.

STOP 3-5 *Ledge below Mount Fosthall*

Elev. 7,000 feet (2,135 m)

Quartzite, marble, calc-silicate succession similar to, but much more extensive than have been seen in the infolds within the core zone. Small folds are cylindrical with strong mineral lineation parallel with fold axes. Note large-scale Fosthall fold with steep south limb and gentle north limb.

Flight from Stop 3-5 to Revelstoke — Fly along Fosthall fold and look along the fold axis. Note north limb with moderate southerly dips and south limb vertical to

overturned. Fly at about 7,500-8,000 feet (2,300-2,440 m) along west side of crest of the range.

Note:

1. Migmatization of a strip of core zone between the Gladsheim Lake infold and mantling gneisses to the west diminishes northward. Evidence of relative movement between core zone and mantling gneiss also diminishes northward and it is concluded that here the core zone did not move relative to the mantle.

2. Note the first occurrence of a north-verging fold immediately west of Cranberry Mountain. Southward, west of the culmination of the domal structure, such folds are not found. North of this point they are plentiful.

NIGHT AT REVELSTOKE

Day 4: Northern Selkirk Mountains

This segment of the excursion, a flight from Revelstoke to Valemount, via Mica Dam, illustrates the Selkirk Fan structure (Figs. 2 and 3) particularly its western or back-folded part, the relationship between the early and late folds, and the structural style and metamorphic grade at various structural levels within the fan structure.

Flight Log, Revelstoke to Mica Dam

Flight from Revelstoke to Stop 4-1, East of Downie Creek — The flight traverses the northern part of the Clachnacudainn salient of the Shuswap Metamorphic complex to the tightly folded and faulted "Imbricate Zone" primarily involving Lower Cambrian strata bordering the salient.

Fly northeast from Revelstoke past Mount Williamson to Mount LaForme. The salient essentially comprises a dimpled dome outlined by a thick sheet of granitoid gneiss overlain by paragneiss containing marker beds of marble and amphibolite. The paragneiss, which generally appears rusty when viewed from a distance, forms a closed synform — the "dimple" — within the dome. The synform is centred north of Clachnacudainn Creek in an area largely occupied by a post-tectonic monzonite pluton that has yielded a minimum K-Ar date of 110 m.y. The grade of metamorphism (which attains sillimanite-muscovite in the salient) decreases rapidly northeastwards from the head of LaForme Creek.

Mount LaForme and the adjoining ridges between the head of LaForme Creek and Carnes Creek display numerous repetitions of limestone, phyllite, and quartzite. Limestone beds attain

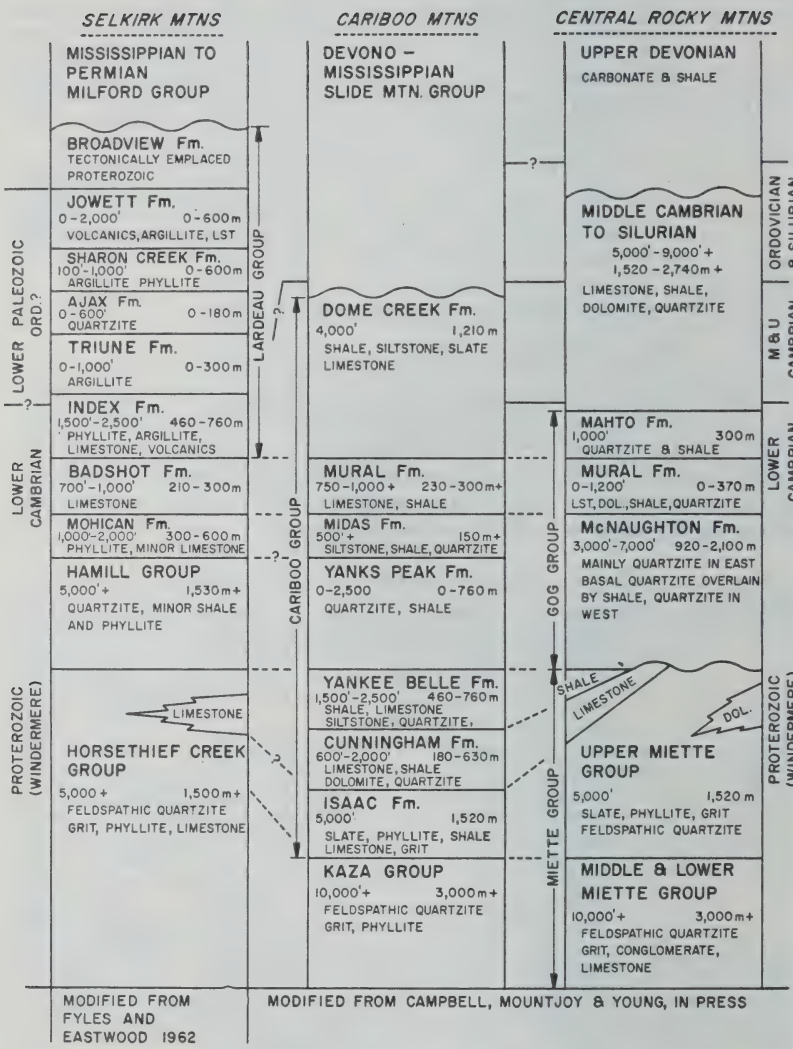

Table 4-1: Correlation of Statigraphic Units of the Selkirk, Cariboo, and central Rocky Mountains.

great thickness as a result of internal deformation and tectonic thickening. The structure of this complex region has not yet been worked out but it is apparent that the oldest unit — the Hamill quartzite — apparently overlies limestone in antiforms and must therefore have been thrust over the Badshot and Mohican Formations prior to being refolded into the southwestern overturned tight antiforms so characteristic of the Imbricate Zone.

Northeast of the Imbricate Zone the black phyllite of the Index Formation is overlain by Windermere phyllitic sandstone and grit, here locally limy, of the Broadview allochthone.

Proceed over the head of Carnes Creek which is underlain by the Broadview Formation and over the ridge to upper Downie Creek. The Lower Cambrian Badshot limestone on both sides of the valley is greatly thickened as a result of internal deformation and thus forms entire mountains such as Mount Moloch to the east and the glacier-hung Mount Carnes and Carnes Tower to the west. Fly past the southern slopes of Mount Holway where the axis of an overturned anticline is bent nearly 90°. The eastern part of this fold trends easterly whereas the western end trends northerly. Continue west of Mount Holway to Stop 4-1.

STOP 4-1
Elev. 7,500 feet
(2,300 m)

About 7 miles (11 km) west of Sorcerer Mountain

The stop is near the nose of a complex, faulted northeast-plunging syncline. Quartzite and pelite of the Lower Cambrian Hamill Group form the mountains to the northwest whereas the overlying carbonates and buff phyllite of the Mohican and Badshot Formations form the ridges to the southeast. Black phyllite of the Index Formation outcrops farther southeast. A short scramble to the ridge southeast of the landing site will reveal tight, similar folds with a strong northeast-dipping axial plane cleavage and northeast plunging axes visible for several hundred feet down the dip slopes to the east. The earliest folds in the western part of the Selkirk Fan structure have this similar style and plunge generally northeasterly. They are on all scales, from the mesoscopic folds visible at this locality to huge steeply northeasterly-plunging folds displayed in the mountain between here and Moloch Creek, about 12 miles (19.5 km) to the southeast. These folds probably represent backfolded, originally westerly-plunging folds of equivalent relative age and style displayed at structurally lower levels beneath the backfold in the northern Selkirks near Stop 4-3.

Flight from Stop 4-1 to Stop 4-2 — Proceed southeast past Mount Holway and turn east between the unnamed high limestone peak and Mount Moloch and fly down Moloch Creek. Spectacular cliffs in the Badshot limestone are displayed on Mount Moloch. Mount Graham, south of Moloch Creek, is underlain by Badshot limestone overlain by black phyllites of the lower Paleozoic Index Formation. Peaks farther south comprise porphyritic quartz monzonite of the Fang Creek stock that has yielded a K-Ar date of 165 m.y.

The mountains north of Moloch Creek display large steeply plunging folds with brownish Hamill quartzite and pelite in the cores of the anticlines, overlain to the southeast by the spectacular dark grey and light grey-to-white marble of the Mohican and Badshot Formations, which are overlain farther southeast by phyllites of the Index Formation that underlie much of the lower slopes of Moloch Creek Valley. Turn north towards Tangier Pass where the slopes to the west reveal a steeply plunging anticline outlined by Hamill quartzite with greenstone in the core.

From Tangier Pass fly eastward south of Mount Sorcerer to Mountain Creek. The mountains between are underlain mainly by Hamill quartzite deformed into northwest-trending folds overturned to the southwest. The section on Mount Sorcerer is inverted with Hamill Group overlying the Badshot limestone.

Continue across Mountain Creek Valley whose lower slopes are composed of Windermere phyllites of the Horsethief Creek Group which are overridden along the Argentine Fault (slide) by inverted strata of the Lower Cambrian Hamill Group. Proceed east over quartzite of the Hamill Group which forms the mass of Mount Iconoclast on the gently dipping southwest limb of the asymmetrical Ventego syncline. Turn north and fly along the synclinal axis past Mount Iconoclast. Nearly vertical strata of the east limb are exposed on the right. Then bear northwest across Bachelor Creek to the west end of the Mount Argentine massif. There crumpled and overturned quartzite of the Hamill Group are truncated below, along the Argentine Fault (slide) against the underlying phyllite of the Windermere Horsethief Creek Group.

Proceed westward over southwestward overturned flexural flow folds in the Hamill Group that are N-shaped when looking north and that climb eastward in a similar manner to the 2nd phase folds in the Kootenay Arc.

Continue westward across a generally northeast-dipping zone in which Hadrynian phyllite and

Lower Cambrian strata are repeated. The Lower Cambrian strata here contain the greatest development of greenstone in the Cambrian. The greenstone, readily visible as greenish outcrops, is commonly amygdaloidal and locally contains sheared pillows. The sharp peak to the west is Downie Peak which is underlain by steeply northeast-dipping Badshot limestone.

STOP 4-2 — *4 miles (6.4 km) east-northeast of Downie Peak*
Elev. 7,000 feet (2,135 m)

View across Goldstream River to the northwestward continuation of the zone of repeated Windermere and Lower Cambrian strata. There the strata, outlined by white and grey Windermere marble beds, dip eastward. Farther north, however, the strata swing northeast and dip southeast. At the head of French Creek they swing back to a northwesterly trend but with a southwestward dip, thus outlining a regional deflection. The earliest folds in the segment north of French Creek plunge northeastward. Later folds in general plunge to the southeast. The regional deflection is interpreted as resulting from a huge southeast-plunging backfold which has refolded westerly-trending 1st phase folds. The latter, preserved in the deeper, more highly metamorphosed southwest-dipping segment, have been rotated on the upper limb of the backfold so that they plunge northeast. The rotated backfold limb comprises the western part of the Selkirk Fan structure.

Flight from Stop 4-2 to Stop 4-3 — Fly across the Goldstream River and up the southeast side of French Creek Valley past southeast-dipping strata. Lower Cambrian quartzite is visible as blocky, lichen-covered outcrops whereas Windermere strata comprise pelitic rocks and limestone. The grade of metamorphism increases northeastward up French Creek. First phase folds are revealed locally by converging and coalescing beds of marble. Later folds are relatively open and upright.

Just below the glacier at the head of French Creek the strata swing sharply to the northwest. Fly across the French Icefield. The ridge bounding it to the northeast is underlain by Lower Cambrian quartzite dipping to the southwest. Continue over glacier at the head of Normanwood Creek to Stop 4-3.

STOP 4-3 — *In Saddle between Normanwood Creek and the west fork of Windy Creek*
Elev. 7,450 feet (2,270 m)

Outcrops here are in the core of the metamorphic culmination of the northern Selkirk Mountains, typically represented by quartz-biotite-muscovite-garnet-sillimanite schist and gneiss. The rocks reveal a complex mesoscopic fold pattern resulting from the intersection of westerly and northwesterly trending similar folds.

Marble beds, some of which are visible on the mountains to the north and southeast, outline highly attenuated westerly plunging 1st phase folds. These early folds are redeformed by northwest-trending folds that, north of the Adamant batholith, generally plunge to the northwest.

Flight from Stop 4-3 to Stop 4-4 — Fly along marble bed over ridge to the north. An attenuated 1st phase fold is outlined by the convergence and coalescence of two marble beds in the cirque north of the ridge.

Fly northeast down Windy Creek, past the mouth of Austerity Creek to where light grey outcrops of nepheline syenite gneiss are visible on both sides of Windy Creek. Turn northwest and follow nepheline syenite gneiss towards Mount Trident. The nose of an undulating recumbent anticline is exposed on the northeast side of Mount Trident. Land on spur north of Mount Trident.

STOP 4-4 *¾ mile (1.2 km) north of Mount Trident*
Elev. 6,900 feet
(2,105 m)

Outcrops here are of quartz-mica-kyanite schist. To the north, across the valley, may be seen the synformal nose of the undulating northwest-plunging fold which contains nepheline syenite gneiss in its core. Parasitic recumbent folds in the upper limb of the fold can be seen on the peak to the west. These folds are characteristic of the structural style of the more highly metamorphosed and more ductile environment of the northern Selkirk Mountains, in contrast to the concentric fold-thrust sheet style of a more brittle environment of the Dogtooth and central Selkirk Mountains.

Flight from Stop 4-4 to Mica Creek — Follow the Rocky Mountain Trench with brownish biotite-rich metamorphic rocks of the Selkirks to the west and Lower and Middle Cambrian quartzites, slates, and carbonates of the Rocky Mountains to the east. Note that the Trench here is narrow with interlocking spurs, in contrast to the broad flat-bottomed valley south of Donald.

Flight Log, Mica Dam to Valemount

This segment of the excursion follows the Canoe River in the Rocky Mountain Trench from the Big Bend of the Columbia River to Valemount. Here the Trench is a sharp V-shaped valley not at all like the broad flat-floored valleys south of Golden and north of Valemount. One or more faults lie within or on the sides of this part of the Trench (Figs. 2 and 3).

Mica Dam to Stop 4-5 — Brownish weathering Middle Cambrian carbonate and shale of the Chancellor Formation form prominent peaks east of the Trench for

many miles north of the Big Bend. These rocks lie in the core of a syncline and are flanked on the east by Lower Cambrian quartzite of the Gog Group. The western limb of the syncline, near the limit of timber, is cut by the northern extension of the Purcell Fault that places metamorphic rocks of the Windermere Kaza Group (equivalent to the Horsethief Creek Group of the Selkirk Mountains) against the Chancellor Formation. The metamorphosed (staurolite-kyanite) Kaza Group underlies the Trench and outcrops in the Monashee Mountains to the west. Metamorphic effects extend well into the Rocky Mountains (Fig. 2).

South of "The Cherries", the Chancellor Formation is cut out by the fault which involves a mass of feldspathic granitoid gneiss of unknown age (Malton Gneiss) in the hanging wall. The gneiss forms the northern end of the Monashee Mountains and underlies part of the Trench as well as a small part of the Rocky Mountains.

STOP 4-5

This stop is on the Monashee Mountains about opposite "The Cherries". On the north facing wall of a glaciated basin the upper contact of the Malton Gneiss is clearly exposed. The contact is marked by a narrow strip of light-coloured mylonite. The foliation or layering in the grey gneiss beneath the south-dipping contact is truncated along the contact whereas that in the overlying brownish or rusty metamorphosed beds of the Kaza Group is apparently parallel to the contact, though in detail it too is truncated.

The gneiss at the stop is a hornblendic and highly feldspathic (plagioclase and perthitic K-feldspar) foliated rock interspersed with thin layers of biotite schist. Feldspar constitutes as much as 70% of the gneiss. Epidote is common.

In the Rocky Mountains the folded contact of the gneiss overlies a thin but apparently continuous sheet of Gog Group quartzite which in turn lies above the Windermere Miette Group (equivalent to the Kaza Group). This contact is thought to be the Purcell Fault and, although the foliation or layering is sub-parallel to it, small angular discordances can be observed.

The rocks immediately surrounding the gneiss are highly folded and contain staurolite and kyanite. In the Rocky Mountains both the grade of metamorphism and the intensity of folding decrease away from the body of gneiss and seem to form an aureole around it. This is particularly evident in the Miette Group in which overturned isoclinal folds pass into open, upright folds beneath the Gog Group farther east.

Flight from Stop 4-5 to Valemount

North from "The Cherries" the route follows the Rocky Mountain Trench. Highly folded Miette Group beds can be seen in the Rocky Mountains and grey outcrops of Malton Gneiss in the Monashee Mountains. Within the gneiss rusty layers of staurolite-kyanite schist are visible. These are thought to be septa or infolds of Windermere rocks.

Along the front of the Cariboo Mountains opposite Valemount light-coloured outcrops of marble low in the valley are believed to be Middle Cambrian Chancellor Formation in the footwall of the Purcell Fault. The overlying rocks are of the Kaza Group and the Malton Gneiss is not present.

NIGHT AT VALEMOUNT

Kamloops to Valemount

A brief description of the terrain between Kamloops and Valemount is included here. Should poor flying conditions occur, this part of the excursion may require modification, in that the journey from Revelstoke to Valemount will be by surface, via Kamloops.

No stops are scheduled for this segment of the excursion and the following remarks deal with broad generalities and a few specific points of interest. A more detailed road log of the Revelstoke to Kamloops segment of the excursion is included in Day 11.

The route follows the North Thompson River most of the way. From Kamloops to Barrière the river is deeply incised into the dissected eastern part of the Interior Plateau. To the west Miocene-Pliocene Plateau lava covers part of the high plateau surface from where it extends westerly and northwesterly over a large area of the central Interior Plateau (Intermontane Zone, Fig. 4). From Barrière to Clearwater the valley marks the boundary between the Interior Plateau and the Columbia Highlands and from Clearwater to Blue River it traverses the Columbia Highlands. The latter appear mountainous and display relief in excess of 7,000 feet (2130 m) but an ancient, deeply dissected plateau surface, perhaps dating from Late Cretaceous or early Tertiary, is clearly evident at a high level. Scattered peaks rise above this old surface.

From Blue River to Valemount the route crosses the Columbia Mountains along the boundary between the Cariboo and Monashee Mountains. In the mountains, where maxi-

mum relief is more than 9,000 feet (2,740 m), remnants of an old surface are sometimes apparent.

From Kamloops to Barrière most of the rocks in roadside exposures and on hill sides are part of the Pennsylvanian and Permian Cache Creek Group. West of the highway, a few miles south of Barrière, is a prominent hill capped by light-coloured Eocene-Oligocene Kamloops Group volcanics. From Barrière north to the village of Little Fort, pillow basalt of the Devono(?)-Mississippian Slide Mountain Group forms brown knobby outcrops on the eastern side of the valley. From Little Fort to Clearwater these rocks are on both sides of the valley and are well exposed along the highway for about 10 miles (16 km) north of Little Fort. Pillow structures are well displayed in some of these outcrops. Just south of Clearwater is a small shelf of flat-lying basaltic lava, a remnant of Miocene-Pliocene flows that flooded the Clearwater River Valley and entered the Thompson Valley.

From Clearwater to Valemount are scattered exposures of metamorphic rocks of various grades including pegmatitic gneiss of the Shuswap Metamorphic complex.

NIGHT AT VALEMOUNT

Day 5: Cariboo Mountains

Introduction

The Cariboo Mountains are the most northwesterly of the four northerly trending mountain ranges of the Columbia Mountains that lie en echelon along the southwestern side of the Southern Rocky Mountain Trench (Fig. 2). Beyond the northern end of the mountains the Trench merges with the topographically subdued and low Interior Plateau and ceases to exist as a definable physiographic feature. The southern end of the northern Trench is offset to the northeast where it forms the valley of the Parsnip River in the Rocky Mountains, and continues on a distinctly more northerly trend than the southern Trench (Fig. 4).

The purpose of the Cariboo Mountains segment of the excursion is to demonstrate structural transitions apparently related to structural depth and grade of metamorphism. The transitions are displayed along the length (70 miles, 110 km) of the large gently northwesterly plunging Premier anticlinorium and also across the anticlinorium into the Isaac Lake synclinorium adjoining on the southwest (Campbell, 1970).

Though complicated by faults and obscured by cover in the Rocky Mountain Trench, a similar transition evidently takes place between the anticlinorium and the adjacent parts of the Rocky Mountains.

In a general way the structural transitions occur between the highly deformed metamorphic rocks near the northwestern margin of the Shuswap Metamorphic complex and the simple structures, characterized by faulting and concentric folding, that are located in a structural and "thermal" saddle between the Shuswap Metamorphic complex and the Wolverine Metamorphic complex to the northwest.

The rocks consist of a late Proterozoic (Windermere) sequence possibly more than 20,000 feet (6,100 m) thick conformably overlain by a younger Proterozoic and Cambrian succession 8,000 to 9,000 feet (2,440 to 2,740 m) thick. West of the excursion route these rocks are overlain by the Devono-Mississippian Slide Mountain Group and still farther west by the Late Triassic and Early Jurassic rocks characteristic of the Interior Plateau. The Slide Mountain Group contains a local, thick conglomerate but is dominated by masses of pillow basalt with chert and argillite of great but unknown thickness. The Slide Mountain Group may have been tectonically emplaced (a slab of ocean floor?) in a late Paleozoic orogeny (cf. emplacement of the Broadview Formation in the Selkirk Mountains). The Mesozoic andesitic, basaltic, and sedimentary rocks in the west lie uncomformably on all older strata. The major deformation and metamorphism involved all of the above rocks including those of Early Jurassic age. Late Cretaceous or early Tertiary coal-bearing beds in the Bowron River Valley were deposited following the major deformation.

The lower part of the Windermere sequence (Kaza Group), more than 10,000 feet (3,050 m) thick, consists commonly of graded beds of feldspathic, matrix-rich, sandstone interlayered with shale. The first three stops are in rocks of this unit.

Flight Log from Valemount to the Cariboo Mountains and return to the Rocky Mountain Trench at Ptarmigan Creek

STOPS 5-1 and 5-2

At the structurally deepest and most highly metamorphosed level of the anticlinorium, immediately west of Valemount, masses of large isoclinal folds are arched across an antiform and pass through a fan axis (Figs. 2 and 3). The rocks here are within or just below staurolite-kyanite grade. Foliation and bedding are generally parallel, even in the hinges of the large isoclines. On the southwestern

flank of the antiform the metamorphic grade decreases to biotite-chlorite grade. The folds become progressively more open, and foliation is sub-parallel to the axial surfaces. On this flank is a second fan axis (Figs. 2 and 3).

STOP 5-1 Elev. 7,000 feet (2,135 m) — The stop, on the east side of the valley of Tete Creek, affords a good view of the easterly fan axis where the isoclinal folds are well displayed. Kyanite is present in the schists in the vicinity.

STOP 5-2 Elev. 6,500 feet (1,980 m) — The view from near the head of Kiwa Creek, is of the antiform across which the isoclinal folds are arched and warped. The rocks are garnetiferous and staurolite occurs sparingly.

Flight from Stop 5-2 to 5-3 — Down plunge to the northwest the antiform becomes a broad anticline with cleavage parallel to the bedding and few if any obvious smaller folds. This can be clearly seen on the north side of the valley of Raush River. The Kaza Group rocks in the anticline are at the lower limit of the garnet grade. In lower grade rocks to the west relatively open folds with axial plane or fanned cleavage are developed on the flank of the anticline. These pass through the southwesterly fan axis beyond which they are inclined or overturned toward the southwest (Figs. 2 and 3). On the northeastern flank of the anticline higher grade rocks are deformed into much tighter folds.

STOP 5-3 Elev. 6,900 feet (2,105 m) — This stop is just east of Mount Quanstrom where Kaza Group rocks are below garnet grade. On the valley wall to the north is a series of large folds inclined or overturned toward the southwest. The angular relation of bedding and cleavage is visible even from a distance.

Flight from Stop 5-3 to 5-4 — The next higher structural level to the northwest in the down-plunge direction along the axis of the anticlinorium features very large similar or composite folds with foliation subparallel to axial surfaces in chloritic Kaza Group rocks. The axial surfaces of these folds are steeply dipping and are disposed in a broad fan so that those on the west flank of the anticlinorium dip northeastward, those on the east dip southwestward, and those in the center are near vertical. Thus the axial surfaces of these folds are roughly normal to the enveloping surface of the anticlinorium and hence to the surface of the structurally deeper anticline and to the limbs of the isoclinal folds at the deepest level (Fig. 3).

At the level of the large similar folds distinctive younger Windermere rocks (Isaac Formation) are involved in the structures. This is a pelitic sequence 5,000 feet (1,525 m) thick which mimics the form of the large folds in the underlying Kaza Group but which does not transmit the form of these folds much above the enveloping surface of

the old unit. From the flight the folds are prominently visible and near Mount Halvorsen the dark Isaac Formation is clearly visible in the core of a large, tight syncline. Mount Halvorsen itself marks a large anticline in which Kaza Group strata are drag folded.

Between Mount Halvorsen and Stop 5-4 note the relatively subdued and rounded character of the topography underlain by the Isaac Formation to the north compared to the more rugged mountains formed of Kaza Group rocks to the south. In the distance ahead and far to the north more rugged mountains are carved from more competent younger units.

STOP 5-4
Elev. 7,000 feet (2,135 m)

This stop, about mid-way between Mount Halvorsen and Mount Amos Bowman, is in very low-grade cleaved rocks of the Isaac Formation. Across a fault just to the north is a small remnant of the basal part of the overlying carbonate of the Cunningham Formation and similar remnants capping several hills can be seen to the northwest toward North Star Mountain. The rocks above the Isaac Formation in this region are essentially unmetamorphosed. They comprise a conformable succession from Proterozoic (Windermere) to Upper Cambrian about 9,000 feet (2,740 m) thick which contains several relatively competent units. The base of the Cambrian cannot be precisely defined but is near or below the base of the archeocyathid and trilobite-bearing carbonate of the Mural Formation.

This stop provides an opportunity to observe profound changes in the character of the deformation from one stratigraphic level to another. Deeper parts of the Isaac Formation are highly folded at Mount Halvorsen and in the mountains directly on trend from this point, to the southeast, but near the top of the formation, the beds are little deformed as on the ridge northwest of stop 5-4 and also low in the valley to the west where they underlie gently folded Cunningham Formation and younger units in the Isaac Lake synclinorium. The relatively competent Cunningham Formation and some of the younger units (e.g. quartzite of the Yanks Peak Formation) suffered largely brittle deformation in contrast to the underlying rocks. They are cut by many steep or vertical strike faults between which the strata are tilted and locally folded (stops 4, 5, 6). The faults apparently do not extend deeply down into the cleaved and folded older rocks.

Flight between Stops 5-4 and 5-5 — Between Stop 5-4 and North Star Mountain the faulted and tilted rocks of the Isaac Lake synclinorium lie to the west and gently dipping Cunningham Formation caps peaks to the east. On the southwestern peak of North Star

Mountain a fault separates west dipping Cunningham and overlying Yankee Belle Formation on the northeast from east dipping Cunningham and Isaac Formation on the southwest.

STOP 5-5 Elev. 6,500 feet (1,980 m) is six miles (9.6 km) north of North Star Mountain and 3 miles (4.8 km) southwest of Mount Hammell. The stop is on the northeastern limb of a large, clearly defined anticline in the Cunningham Formation and the well-bedded upper part of the Isaac Formation. The Isaac Formation is highly cleaved in the core of the fold but the overlying carbonate is apparently deformed primarily by flexural-slip folding. The anticline is cut on both limbs by strike faults. The rocks at the stop are Cunningham limestone.

This locality affords a good view of the highest level of the Premier anticlinorium to the west, north and east and provides also a vista to the southeast across the folded Isaac Formation to the rugged hills underlain by the large folds of the Kaza Group (between Stops 5-3 and 5-4) which are directly upplunge on the structural trend. At this level the anticlinorium and the adjoining Isaac Lake synclinorium involve the same strata hence the structures lose their individual identities and merge in a broad, highly faulted plate. The structural relief within the plate is not large; the northwest trending faults have stratigraphic separations of as much as 10,000 feet (3,050 m) but most have less than 5,000 feet (1,525 m). The faults are almost all steep or vertical and, assuming mainly vertical movements, the panels between them are effectively a series of grabens and horsts, though this is perhaps an oversimplification.

Mount Hammell exhibits a plate of gently dipping Yanks Peak Formation quartzite overlain by the recessive Midas Formation and capped by two small patches of Mural Formation limestone. This panel is separated by a fault from the next mountains to the west, within which are folded and faulted rocks of the Isaac, Cunningham and Yankee Belle Formations including the fold at stop 5-5. A prominent conical peak farther to the west marks another flat-lying panel involving rocks from the Cunningham to the Mural Formation. North Star Mountain lies on the southeastern extension of this panel.

Flight between Stop 5-5 and 5-6 — At the head of Ptarmigan Creek is a large fold in the Cunningham and Isaac Formations. As the flight turns down Ptarmigan Creek note the fault bounded panel of Mount Hammell to the southeast. Ahead are prominent grey outcrops of the Mural Formation, also in fault bounded panels.

STOP 5-6 is on the upper part of the Mural Formation, 4 Elev. 6,800 feet miles (6.4 km) north-northwest of Mt. Hammell and just north of Ptarmigan Creek. Archeocyathids occur in the limestone. This stop gives an excellent view of the many fault panels to the northwest and southeast. The rocks, though commonly tilted, are not highly folded within individual panels. Cleavage is locally developed in some of the pelitic rocks.

Flight between Stop 5-6 and 5-7 — North of Ptarmigan Creek, opposite the prominent grey rather flat cap of Mural Formation limestone southeast of the creek and about 4 miles (6.4 km) northeast of Mount Hammell, is the thickest known section of Lower Middle (?), and Upper Cambrian Dome Creek Formation. These dark to yellowish shales dip west and are faulted against the Cunningham and Yankee Belle Formation on the west. To the north of the route they conformably overlie the Mural Formation which here is part of an unfaulted sequence that extends well down into the Yankee Belle Formation. The route crosses several more fault panels, in which the carbonate of the Mural and Cunningham Formations are prominent, before leaving the mountains and descending into the Trench to a landing near the highway.

In the Rocky Mountains immediately opposite, the highest peaks are composed of the Gog Group (including the Mural Formation) which, together with the underlying Miette Group, are equivalent to the bulk of the rocks in the Cariboo Mountains. The Gog marks the Mount Robson synclinorium which extends far to the south to Mount Robson and beyond. In this region the folds are overturned and the axial surfaces dip steeply northeasterly. At Mount Robson the axial surface of the syncline dips southwesterly.

Far to the northeast is Mount Sir Alexander where the structure and stratigraphy are typical of the Eastern Main Ranges similar to those in the Jasper-Lake Louise segment of the trip. Just beyond is a narrow Front Range followed by wide Foothills. Southeast of Mount Sir Alexander is a structural culmination in which Windermere Miette Group strata are exposed across the entire width of the Main Ranges. They lie against the Triassic and upper Paleozoic of the Front Range along the Snake Indian Fault.

STOP 5-7 is in the floor of the Trench near Ptarmigan Creek. From here the return trip to Valemount will be by bus along the Trench by way of Highways 16 and 5.

Ptarmigan Creek to Valemount

No stops are scheduled but if time permits cleaved Kaza Group rocks can be observed at Goat River and West Twin Creek. Folded and cross-bedded Gog Group (McNaughton Formation) quartzite is

visible low on the northeast side of the Trench at McBride. This can be examined close to the road about 3 miles (4.8 km) southeast of the town. These rocks apparently lie in a graben in the trench because the rocks on the higher hills on either side of the valley are older Proterozoic strata.

Note the rugged hills in the Cariboo Mountains south of McBride in contrast to the rounded hills to the west and northwest. This is due to the emergence of the Kaza Group from beneath the softer, less resistant Isaac Formation.

The rocks high in the mountains between McBride and Valemount are all of the Kaza Group in the Cariboo Mountains and of the equivalent Miette Group in the Rocky Mountains. The floor of the Trench may be underlain by covered younger strata as at McBride. Light coloured outcrops of marble low on the side of the Trench opposite Valemount may be Middle Cambrian Chancellor Group.

The structural transitions displayed in the Cariboo Mountains seem to demonstrate a very close relationship between the nature or style of deformation and the grade of metamorphism. Added to this is the influence of relatively competent units in the upper, unmetamorphosed part of the section. The rocks below the Windermere carbonate (Cunningham Formation) deformed readily by folding even in low temperature environments (Stops 5-3 and 5-4); in higher temperature environments deformation by folding was extreme (Stops 5-1 and 5-2). The younger rocks, on the other hand, were less prone to deformation by folding under low temperature conditions; they yielded by faulting, tilting and flexural slip folding (Stops 5-4, 5-5, 5-6) apparently in response to stress conditions related to those that produced the intense folding at greater depth. In other parts of the region the younger rocks are severely folded where they are more highly metamorphosed.

These factors suggest that thermal energy was a prime factor in the development of structures in the Cariboo Mountains. The role of mechanical energy in the sense of regional "compressive stress" is difficult to assess.

NIGHT AT VALEMOUNT

Day 6: Mount Robson - Yellowhead Pass - Athabasca Cross Section

Introduction

This cross section of the Rocky Mountains differs from the Kicking Horse segment (Day 1) which is about 160 miles (250 km) to the south, because of changes in stratigraphic

succession and a deeper structural level (Figs. 2 and 3). The main differences are:

1) The Windermere and Lower Cambrian sequences are 3 to 5 times as thick.

2) The Western Ranges of complexly folded Cambro-Ordovician strata and a part of the western Main Ranges disappear against the Purcell Thrust along the Rocky Mountain Trench southeast of Valemount.

3) The western Main Ranges contain thick, shaly, and metamorphic facies of the Windermere (Miette), in contrast to the younger thick Chancellor succession to the south. Cleavage and complex fold patterns are widespread whereas laterally extensive thrusts are rare.

4) The Yellowhead Pass region forms a structural culmination exposing a large area of complexly folded and faulted Miette strata. In this culmination there is a change of structural grain not evident in the Front Ranges, probably reflecting an age difference between the Front and Main Ranges.

5) The Front Ranges between the Athabasca and North Saskatchewan Rivers are more steeply dipping. Where the basin shale facies of the Upper Devonian is present, folding is more prominent in the thrust sheets.

6) Some of the thrust faults and associated folds of the eastern Front Ranges have been rotated from a southwest to a northeast dip.

Log of road stops — Mount Robson to Athabasca Valley

0.0 Valemount

STOP 6-1 *Tete Jaune Cache (Main Ranges Stops 6-1 to 6-8)*

0.3 miles (0.5 km) Folded and cleaved outcrops of middle Miette sandstones occur here, with interbeds of pebble-conglomerate (some exhibiting considerable stretching), siltstone and shale. Well developed foliation is parallel to axial surfaces of generally upright small-scale isoclinal folds. Some of the coarse-grained beds are graded.

Metamorphic biotite occurs on both sides of the Fraser valley for about 5 miles (8 km) east of the Trench. To the southeast near Valemount metamorphism increases to the garnet grade.

Outcrops between here and Mount Robson mostly belong to the middle Miette succession. At least two steep-dipping reverse faults probably cause repetitions within the succession. Near Mount Rob-

son overturned folds may be observed across the Fraser River on the north end of the Selwyn Range.

STOP 6-2
11.0 miles
(17.6 km)

Mount Robson

Mount Robson (Fig. 6-1), the highest peak in the Canadian Rockies, provides a superb section of Middle and Upper Cambrian strata in the west limb of the Mount Robson syncline. More than 9,500 feet (2,900 m) of section is exposed from Kinney Lake at the base (3,230 feet, 985 m elevation) to the top (12,972 feet, 3956 m). The latest Middle Cambrian Waterfowl and Arctomys Formations form the prominent orange-brown weathering recessive band about half way down the mountainside. Above this marker is a nearly complete section of the Upper Cambrian Lynx Formation. Below the Arctomys most of the Middle Cambrian carbonate units (Pika, Titkana, Tatei, Chetang, Hota-Adolphus Formations) are exposed. The tree-covered lower slopes in the foreground to the left and right of Mount Robson are outcrops of the McNaughton Formation (lower part of Gog Group). The thickness of the McNaughton Formation is less than in sections to the north and south suggesting that the section is faulted (probably along a continuation of the Red Pass Thrust). The Mount Robson syncline gradually comes closer to the Trench to the northwest and forms the mountain range

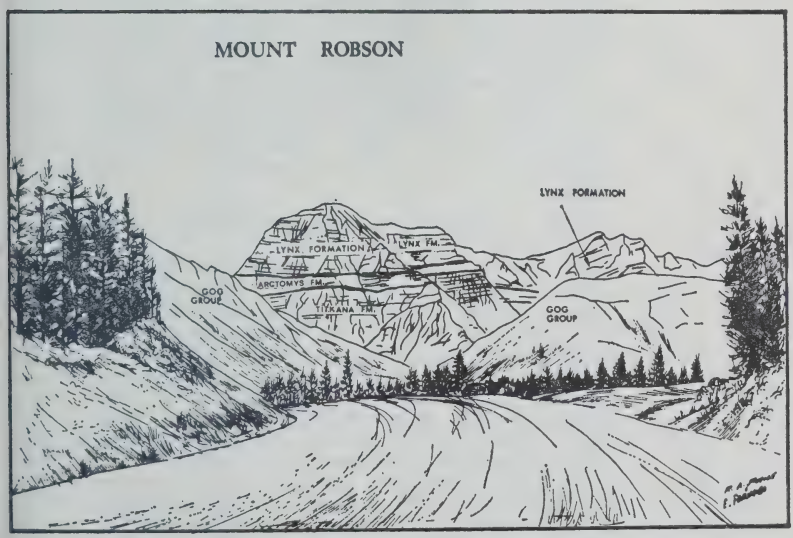

Fig. 6-1. Sketch of the southwest side of Mount Robson from Highway 16 (R. A. Price with E. Fernando).

directly east of McBride. Southeastward, this syncline ends in the Trident Range a few miles southeast of Jasper, some 40 miles (64 km) from the Trench. This dramatically demonstrates the oblique trend of Rocky Mountain structures relative to the Trench and the northwestward disappearance of the Western Ranges and a large segment of the Main Ranges.

STOP 6-3

Upper Miette Group

About two miles (3 km) southeast of the Mount Robson viewpoint, upper Miette Group dark grey argillites dip between 40 and 60 degrees northeast and are presumably in normal position beneath Gog strata which outcrop higher on the mountain side. These argillites contain very fine silt laminations and lenses (flaser bedding) which were probably deposited in a moderately deep marine basin.

Structurally these strata occur in the faulted southwest limb of the Mount Robson syncline. Across the Fraser River in the Selwyn Range folded and faulted middle Miette Group strata continue southeast on that side of the valley to Yellowhead Pass. The stratigraphic throw of the Moose Lake Thrust, which follows the Fraser River valley, is at least 5,000 feet (1520 m) at this locality.

For the next 30 miles (50 km) the route follows along the tectonic strike close to the trace of the Moose Lake Thrust separating Gog or upper Miette strata on the northeast from middle Miette rocks on the southwest. The lower part of the McNaughton Formation weathers to a characteristic deep red colour in the region between here and Jasper. The red colour is a hematite stain, possibly derived from weathering of concentrations of black magnetite sand in the orthoquartzites.

STOP 6-4
42.0 miles
(67.2 km)

Views of Mount Fitzwilliam and Yellowhead Mountain

The core and western limb of the Mount Robson syncline is outlined by the McNaughton Formation and an underlying carbonate unit, the Byng Formation (Upper Proterozoic), possibly a lateral equivalent of the Cunningham Formation of the Carboo Mountains. The quartz sandstones of the McNaughton abruptly overlie the massive dolomites of the Byng Formation which locally contains small stromatolites. On Mount Fitzwilliam these dolomites are about 1,000 feet (305 m) thick, but thin to 500 feet (150 m) on the eastern part of Yellowhead Mountain. On the southwest slopes of Yellowhead Mountain the carbonate thins and disappears through interfingering with sands in the upper Miette, just below tree line. Elsewhere, this carbonate has a sporadic distribution and ap-

pears to represent a series of small carbonate shoals or banks. It also represents a marked change in sedimentary environment from deeper water marine conditions of the upper Miette to beach and fluvial conditions represented by the McNaughton Formation.

Beneath the Byng Formation, at least 2,000 feet (610 m) of recessive upper Miette silty mudstones are underlain by about 3,000 feet (915 m) of middle Miette grits, which are exposed along the road east of Yellowhead Lake. Just north of Mount Robson, along strike, the middle Miette grits are more than 9,000 feet (2740 m) thick in an unfaulted section.

The glaciation disrupted the pre-existing drainage of this region as originally the upper portion of the Fraser River probably flowed eastward into the Miette River but was apparently blocked by a moraine east of Yellowhead Lake. Glaciers, centered near the Cariboo Mountains west of the Rocky Mountain Trench, flowed eastward across the Selwyn Range and down the Miette and Athabasca valleys and deposited Shuswap type metamorphic glacial erratics near Hinton.

STOP 6-5
50.0 miles
(80.0 km)

Moose Pass Thrust at Yellowhead Pass

The Yellowhead Pass (3770 feet, 1150 m) is on the Continental Divide, the boundary between Alberta and British Columbia. At and near the entrance to Jasper National Park are outcrops of typical middle Miette resistant grit units, separated by recessive argillites, siltstones and mudstones. Many of these beds display graded bedding, ripples, cross laminations, and slaty cleavage. Immediately to the east, upper Miette dark grey to pale green silty argillites outcrop and must be separated from the middle Miette to the west by the Moose Pass Thrust. This thrust fault duplicates Miette strata to the north, and southward extends to Fortress Lake, repeating Gog strata west of Mount Edith Cavell.

To the north, in the summits of Mount Bridgland, Monarch Mountain and the Victoria Cross Range and to the south (not visible from the road), in the summits of Roche Noire, the Trident Range and Mount Edith Cavell, Gog strata outline broad open folds or gently dipping thrust sheets. These large and open structures at higher elevations contrast with the complex folded nature of the underlying Miette strata exposed at a lower level along the Miette River valley. This change in structural style may be explained in a number of ways. It is related to the relative incompetence of the Miette Group, as compared to the Gog Group, and the presence of major thrust faults in this region. Whether these major thrusts ex-

tend to depth and form a basal *décollement* along which the Miette Group has been detached from the underlying cratonic basement, or whether these faults splay downwards into two or more *décollement* zones within the Miette Group cannot be determined at present because of insufficient outcrop data. Here and elsewhere the Miette strata have undergone considerable horizontal shortening and penetrative deformation with cleavage, folds and kink-bands. The arenaceous horizons exhibit little shearing as indicated by vertical slaty cleavage and axial surfaces of folds, whereas the argillaceous horizons are strongly sheared.

Yellowhead Pass is near the center of a large structural culmination exposing rocks near the bottom of the sedimentary wedge (Fig. 2) marked by an area of extensive exposure of the Miette Group. There is a change in structural grain from northwest trending structures south and north of the culmination, to west-northwest within the culmination. There is no corresponding deflection of structural grain in the Front Ranges or Foothills, which supports the interpretation that they developed after the Main Ranges. This change in structural grain is related to the metamorphic halo and the area of paragneiss, schist, amphibolite, and gneissic granite (Shuswap type) on the west side of this structural culmination. In the outer metamorphic halo surrounding this metamorphic complex in the northern Selwyn Range, coarse biotite porphyroblasts grew with random orientation across both the schistosity and other foliations in the phyllites. Hence a significant part of the metamorphic recrystallization outlasted the penetrative deformation. Biotites from these rocks yielded a K-Ar date of 111 m.y. This probably places an upper limit on the time of metamorphic recrystallization and the preceding deformation. Thus this part of the Main Ranges had formed before mid-Cretaceous time and probably began to develop as early as Late Jurassic, considering the above dating in conjunction with the record of the Mesozoic clastic wedge and the volumes of sediment eroded from the Main Ranges (Price and Mountjoy, 1970, p. 23).

STOP 6-6
56.0 miles
(89.6 km)

Lower Middle Miette Strata and Structure near Geikie

Eastward the road gradually intersects lower stratigraphic levels. Excellent and nearly continuous outcrops of the lower part of the middle Miette Group (lower Wynd and Old Fort Point Formations of Charlesworth *et al.*, 1967) occur along the highway. The succession here is mostly overturned.

The coarse arenaceous sediments exhibit grading with rip-up clasts, fine laminations and cross lam-

inations in their upper parts, grading into dark colored argillaceous strata, and are suggestive of turbidites.

STOP 6-7
56.5 miles
(90.4 km)

The Old Fort Point Formation will be examined for about 0.5 miles (0.8 km) along the highway. It consists of green slates, purple and green limestones, intraformational limestone, conglomerates, and purple slates with some calcareous sandstones. Similar colored slates and limestone have not been observed anywhere in the region to the west and these rocks may represent a local facies.

These units occur in overturned folds, with axial plane cleavage which form a part of the Meadow Creek anticlinorium. They are offset by a southwest-dipping normal fault. The Monarch Thrust may occur east of this structure, duplicating middle Miette strata. It continues southeast along the Athabasca Valley and becomes the important Simpson Pass Thrust (see day 8).

From here to Jasper, the road cuts across folded middle Miette strata with fold axial planes upright or slightly inclined to the southwest. (Junction with Banff-Jasper highway — mile 65.6, km 105).

STOP 6-8
66.5 miles
(106.4 km)

Jasper

Jasper townsite is located near the axis of the Jasper anticlinorium with Old Fort Point Formation exposed in its core. This anticlinorium is interpreted to be bounded on the east by the Snaring Thrust which joins the Pyramid Thrust southeast of Tekerra Mountain and the Maligne Range.

To the north Pyramid Mountain displays the reddish colored lower McNaughton Formation and the recessive brown weathering silty argillites of the upper Miette. To the northeast the western portion of the upper Paleozoic thrust sheet of the Front Ranges suddenly appears beneath the Pyramid Thrust.

STOP 6-9
75.5 miles
120.8 km)

Near the Palisades (Front Ranges — Stops 6-9 to 6-14)

Two essentially homoclinal thrust sheets are present; the Chetamon (Chetamon Mountain, The Palisades, Roche Bonhomme), and the Colin (Morro Peak and Mount Colin). Strata range in age from Cambrian to Triassic and are predominately carbonates similar to the Front Ranges near Banff, except that here the Fairholme Group consists of a shale (basin) facies. The resistant, massive light grey limestone cliffs above this shale unit belong to the uppermost Devonian Palliser Formation, but can be confused with similar but darker weathering cliffs near the top of the Middle Cambrian sequence.

From southeast to northwest the Chetamon Thrust changes in stratigraphic position from the Upper Cambrian to a level about 5,000 feet (1520 m) stratigraphically lower in the upper part of the Gog Group. An anticline-syncline pair on Roche Bonhomme is associated with this change.

STOP 6-10
78.3 miles
(125.3 km)

Cold Sulphur Springs in Colin Thrust Sheet

The springs emerge near the top of the Upper Devonian Flume stromatoporoidal carbonates which formed a foundation on which the 'reef' complexes developed in the Colin Thrust sheet to the north (Ancient Wall reef complex), and in the Miette Range (Miette reef complex) to the east. They are surrounded and overlain by basinal sediments, the lower part of which are euxinic black shales (Perdrix Formation). These Upper Devonian sediments rest with profound unconformity on Cambrian strata whose exact stratigraphic position is difficult to determine (see road outcrops).

The northward extension of the Colin Thrust sheet together with minor splay faults can be observed across the Athabasca Valley. The next thrust sheet to the northeast is the Greenock.

STOP 6-11
87.4 miles
(139.8 km)

Rocky River and Jasper House

The excellent view of the west side of the Miette Range illustrates three to four repetitions of the Upper Devonian Palliser Formation due to southwest rotated folds and thrust faults. The Rocky River and Snake Indian valleys are underlain by Mesozoic strata thickened by imbricate thrust slices.

The monument commemorates the second site, directly across the Athabasca River, of the Hudson's Bay Co. trading post known as Jasper House occupied from 1826 to 1884. The original site, occupied from 1801 to 1826, was downstream at the north end of Brulé Lake.

STOP 6-12
90.3 miles
(144.5 km)

Disaster Point

Here an anticline occurs in Lower Carboniferous and Upper Devonian strata with a southwesterly overturned limb. Prominent slickensides which developed during concentric folding occur in the Palliser Formation. This anticline is bounded on the northwest by the vertical to overturned Disaster Point Thrust, which has been brought into its present position through rotational motion of underlying thrust sheets and local folding. Cleaved and folded Mount Hawk argillaceous carbonates occur in the footwall of this fault.

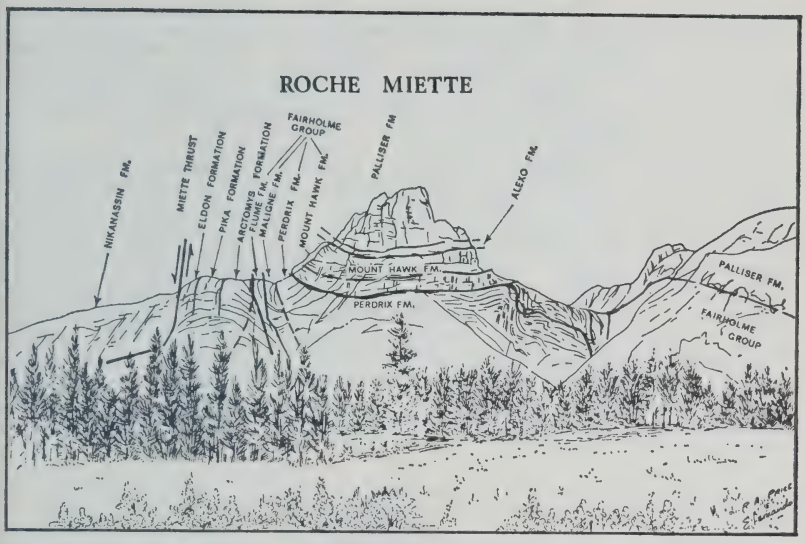

Fig. 6-2. Sketch of Roche Miette from Highway 16 (R. A. Price with E. Fernando).

To the northwest, across the Athabasca Valley, the extension of this structure occurs at a higher stratigraphic level in Roche à Bosche and nearby mountains.

STOP 6-13
90.7 miles
(145.1 km)

Roche Miette

The Miette Thrust sheet is the continuation of the McConnell structure from the Banff region (see Price and Mountjoy, 1970). Roche Miette (Fig. 6-2) consists of a syncline and southwest overturned anticline. These folds are disharmonic, the syncline in the Palliser Formation which forms the peak of Roche Miette occurring directly over the anticline in the Flume Formation (both units Upper Devonian), and they have been rotated between 30° and 45° southwestward. Compare with Roche Ronde on opposite side of valley. These structures illustrate the predominance of folds in thrust sheets in the shale facies of the Upper Devonian Fairholme Group.

The Miette Thrust occurs on the east side of the mountain just below the resistant Middle Cambrian Titkana limestone. These strata have been thrust over the Jurassic Nikanassin Formation. A condensed Middle Cambrian sequence occurs beneath Upper Devonian strata, illustrating the eastward truncation beneath the sub-Devonian uncon-

formity of the entire Upper Cambrian, Ordovician and Silurian succession. To the northeast is a broad recessive weathering valley underlain by Mesozoic strata. Another southwest overfold (Moosehorn) is visible in the distance (Fig. 6-3). (Road junction with road to Miette Hot Springs — mile 92.6, km 148.2).

En route to Roche à Perdrix note the Moosehorn overfold (Fig. 6-3) across the river and the Ashlar Ridge homocline; both represent a fault slice within the southwest limb of the Perdrix anticline. The Moosehorn fold consists of two narrow anticlines with axial planes dipping about 70° northeast. The Moosehorn structure and adjoining syncline to the northeast are spatially directly related to changes in stratigraphic position of the underlying Ashlar Thrust from within the Middle Cambrian to within the Upper Devonian.

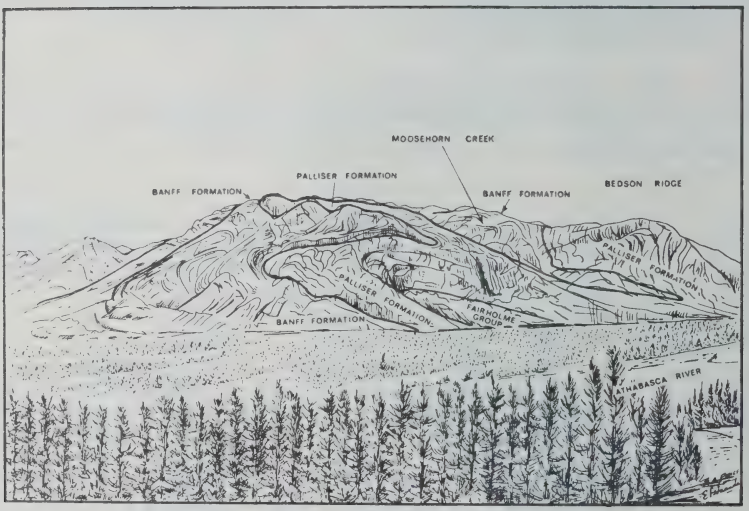

Fig. 6-3. Sketch of southwesterly overfolds in Boule thrust sheet at Moosehorn Creek from near Pocahontas (R. A. Price with E. Fernando).

STOP 6-14
97.0 miles
(155.2 km)

Roche à Perdrix

Roche à Perdrix (Fig. 6-4) is a complex faulted double syncline-anticline pair. The western fold pair are asymmetric and partly overturned to the southwest. They form the main part of the mountain and like Roche Miette exhibit disharmonic folding with the syncline in the Palliser of the peak occurring above an anticline in the Flume Formation.

On a ridge northeast of Roche à Perdrix the Boule Thrust is flat lying with Mississippian Rundle strata occurring above crumpled late Jurassic Nikanassin sandstones. Comparable structures occur across the Athabasca valley on Boule Roche, except the folds have southwesterly dipping axial planes. They illustrate the rapid changes which can occur along strike. These structures are readily observed from the Overlanders Motor Lodge (mile 98.5, km 157.6) where structural relationships on geological maps and cross sections and photographs will be discussed.

To the east is another Paleozoic thrust sheet (Rocky Mountain Foothills) marked by the prominent Folding Mountain anticline. A well, drilled on the southwest flank of the anticline, penetrated a thrust fault at a depth of 4,900 feet (1495 m) which has brought Upper Devonian Cairn Formation over Lower Cretaceous strata. Beyond this is a series of Upper Cretaceous sandstone ridges underlain by the Brazeau Thrust.

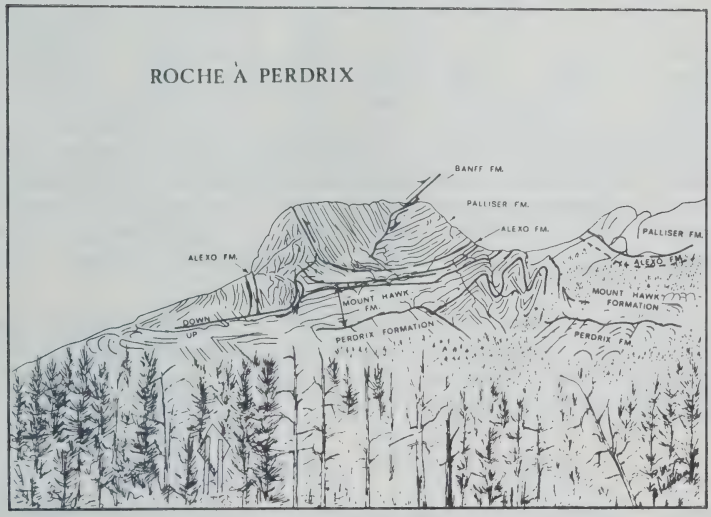

Fig. 6-4. Sketch of Roche à Perdrix from Highway 16 at the east entrance to Jasper National Park (R. A. Price with E. Fernando).

NIGHT AT OVERLANDERS LODGE

Day 7: Front Ranges Near Miette Hotsprings and Jasper

The morning will be spent hiking or riding up a low mountain ridge east of the Miette Range, a structural continuation of Ashlar Ridge, to view structures and stratigraphy of the surrounding ranges (structures within a 30 mile, 50 km radius can be observed). In the afternoon, after a swim in the Miette Hotsprings, there will be opportunity for photography along the scenic Athabasca valley, and for shopping in the resort town of Jasper.

Skyline hike

The hike takes about 4 hours for the round trip, along an excellent trail from an elevation of about 4,500 feet (1370 m) through a light pine forest to an elevation of about 6,500 feet (1980 m) immediately above timber line.

Unfortunately few outcrops are exposed but the superb views more than make up for this deficiency. Folds, faults and stratigraphy are magnificently displayed in all directions. Portions of the Boule, Mystery Lake, Nikanassin, Miette and McConnell Thrust sheets can be observed. In addition the change from shale to carbonate facies at the north end of the Upper Devonian Miette reef complex occurs in Utopia Mountain and adjacent mountains. Folds die out with this change to carbonate facies. Large glacial erratics derived from the Gog Group attest to the complete covering of these mountains by a Cordilleran ice sheet during part of the Pleistocene.

The hike will end at the Miette Hotsprings where those who wish can take a relaxing swim. Alternatively the Carboniferous succession can be examined along the eastern continuation of the trail.

NIGHT AT OVERLANDERS LODGE

Day 8: Main Ranges, Jasper-Lake Louise via Banff-Jasper and Trans-Canada Highways to Revelstoke

The route follows along strike within the eastern part of the Main Ranges of the Rocky Mountains (see introduction to Day 1) near the trace of the Simpson Pass Thrust (Fig. 2). The gradual, regional plunge of these structures can be observed; first to the southeast away from the structural culmination west of Jasper towards the structural depres-

sion near the Columbia Icefields and Sunwapta Pass; and second, a northwest plunge as another structural culmination is approached west of Banff. This route also permits comparisons of footwall and hangingwall structures along strike, and of structures from one stratigraphic level to another. Relatively few structural changes take place in comparison with other parts of the deformed belt. Some of the prominent normal faults characteristic of the Main Ranges are well displayed along this route and there are only minor changes in the stratigraphic succession (compare Figs. 8 and 9).

0.0 From Jasper to the first stop, outcrops of middle and upper Miette strata will be crossed, all with southwest dips and with essentially similar lithologies to those observed west of Jasper (Day 6). Near Mount Kerkeslin the basal beds of the McNaughton Formation (Gog Group) and the Tangle Ridge normal fault are crossed.

Log of Road Stops — Jasper to Field

STOP 8-1
24.7 miles
(39.5 km)

Athabasca Falls and Mount Kerkeslin

Athabasca Falls provides a section of the arkosic and conglomeratic lower part of the McNaughton Formation with good examples of trough and planar cross bedding. The Gog Group continues from here to about 1,500 feet (450 m) below the top of Mount Kerkeslin and is in the order of 6,000 feet (1830 m) thick. The Middle Cambrian consists of a series of cycles of limestones interbedded with shale and argillaceous limestones. Below this is a prominent limestone with red bands (Peyto limestone) which contains a late Early Cambrian *Olenellus - Bonnia* fauna. About 750 feet (230 m) below the Peyto is the 70-foot (21 m) Mural limestone with archaeocyathids and Asian olenellid forms. This is the oldest Cambrian faunal horizon in this part of the Main Ranges. The recumbent syncline at the top of Mount Kerkeslin (Fig. 8-1) suggests that the Simpson Pass Thrust passed just above the peak.

STOP 8-2
30.0 miles
(48.0 km)

Athabasca Valley — a panoramic view

To the north is Mount Kerkeslin, the Simpson Pass Thrust in the valley, and Mount Edith Cavell in the distance. To the left is an imposing range with Mounts Christie (10,180 feet, 3105 m) and Fryatt (11,026 feet, 3363 m) with Middle Cambrian carbonates underlying the crests and the lower tree-covered slopes underlain by Gog sandstones. To the east the Tangle Ridge normal fault downdrops Middle Cambrian carbonates on the west against Lower Cambrian sandstones on the east.

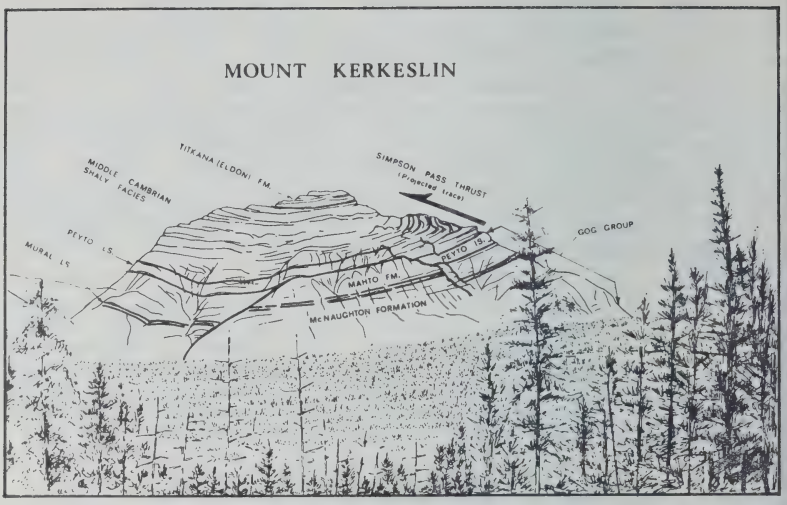

Fig. 8-1. Sketch of Mount Kerkeslin from Athabasca Falls (R. A. Price with E. Fernando).

Ahead the road crosses the normal fault just beyond the Sunwapta Falls turnoff. The road then leaves the Athabasca Valley (and the Simpson Pass Thrust) and follows the Sunwapta River. To the east the prominent dip slopes of Endless Chain Ridge are formed of red and grey weathering sandstones of the lower part of the Gog Group.

STOP 8-3
51.0 miles
(81.6 km)

Tangle Ridge

The Tangle Ridge normal fault can again be observed on the north end of Tangle Ridge — can you identify it? Note how well units in the Ordovician and Upper Cambrian correlate with those lower in the succession. The Simpson Pass Thrust enters this valley, crossing the mountain ridge to the west; an overturned anticline in upper Gog and Middle Cambrian strata occurs in the hangingwall of this fault.

Both the normal fault and the Simpson Pass Thrust can be traced south to Peyto Lake (Stop 8-7).

STOP 8-4
65.0 miles
(104 km)

Athabasca Glacier and the Columbia Icefields

The mountains adjacent to the Athabasca Glacier comprise Middle Cambrian massive carbonates. To the left on the northeast slopes of Mount Athabasca, the Simpson Pass Thrust crosses be-

tween the ice covered side underlain by Middle Cambrian strata and the bare ridge underlain by Upper Cambrian and Ordovician beds. On the extreme left in line with the highway, Devonian and Carboniferous strata form a syncline on the crest of Tangle Ridge. This is close to the center of the structural depression. Outcrops near the Information Center are the red and green shales and orange-weathering dolomitic siltstones characteristic of the Arctomys Formation (near the top of Middle Cambrian succession).

After crossing Sunwapta Pass the road crosses the Tangle Ridge syncline and approaches the Tangle Ridge normal fault.

STOP 8-5
78.5 miles
(125.6 km)

Cirrus Mountain

A branch of the Tangle Ridge normal fault crosses Cirrus Mountain near the axis of the syncline. The succession on the west side consists of a thick sequence of Lower Carboniferous (Rundle and Banff Formations) and Upper Devonian (Palliser Formation, Fairholme Group) strata. On the east side of the fault the stratigraphic succession begins at the top with the Palliser Formation and continues down into the Ordovician. To the west out of view is the margin of another Upper Devonian

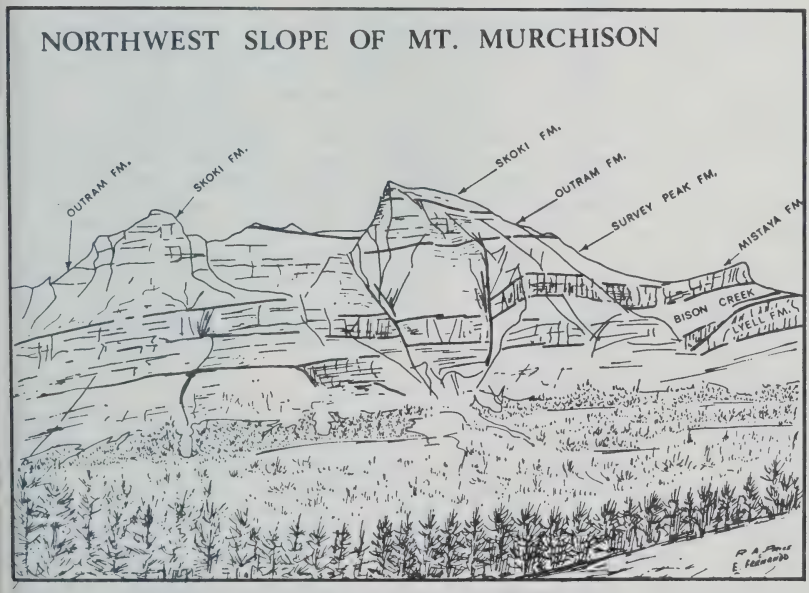

Fig. 8-2. Sketch of the northwest slope of Mount Murchison from Highway 93 at Mount Wilson (R. A. Price with E. Fernando).

'reef' complex with basin shale facies (near Sunwapta Pass) changing southeast to carbonates at the Big Bend and at the base of Cirrus Mountain.

From Cirrus Mountain to the North Saskatchewan River the route gradually descends through Devonian, Ordovician, and Upper Cambrian successions.

STOP 8-6 — *North Saskatchewan River Crossing*

96.4 miles (154.2 km)

A) Mount Murchison (Fig. 8-2) to the southeast provides magnificent exposures of Ordovician and Upper Cambrian formations (Skoki Formation at the top and Waterfowl and Arctomys Formations near the base). The prominent putty grey, recessive weathering unit about halfway down the mountain is the Survey Peak Formation which is the basal unit of the Ordovician succession. Several normal faults with small displacements form a horst-like feature in the gully on the northwest face. Mount Wilson behind the bungalows exhibits the same stratigraphic sequence with the addition at the top of the Mount Wilson Quartzite above the Skoki Formation.

98.8 miles (158.1 km)

B) View of Mount Wilson (Fig. 8-3) about 2 miles (3 km) further along, from base of Mount Murchison.

This vantage point provides a better view of Mount Wilson, which exhibits a sequence from Upper Devonian (Cairn Formation) to uppermost Middle Cambrian (Waterfowl Formation). These thick, predominantly carbonate sections, in contrast to much thinner sections immediately to the east in the Front Ranges, provide evidence for postulating a sedimentary hinge line near the Main Ranges-Front Ranges boundary, and interpreting the thick succession to the west as a miogeocline.

Just out of view on the right is the Pinto Lake normal fault, west side down, similar to the Tangle Ridge fault. Road outcrops consist of thin-bedded limestones and massive dolomites belonging to the Middle Cambrian Pika and Eldon Formations.

STOP 8-7 — *Peyto Lake*

119.3 miles (190.9 km)

Northwest from picturesque Peyto Lake (6,120 feet, 1,867 m) is a panoramic view of the route travelled from Mount Wilson (Fig. 8-4), illustrating the trace of the Simpson Pass Thrust (dips about 40° southwest) and the northwest plunge of the Main Ranges structures. To the west is a continuous section from the Gog to high in the Upper Cambrian (Lyell Formation). Outcrops of Gog sandstones occur near the viewpoint. Peyto Glacier descends from the Wapta Icefield and is the main source of the Mistaya River.

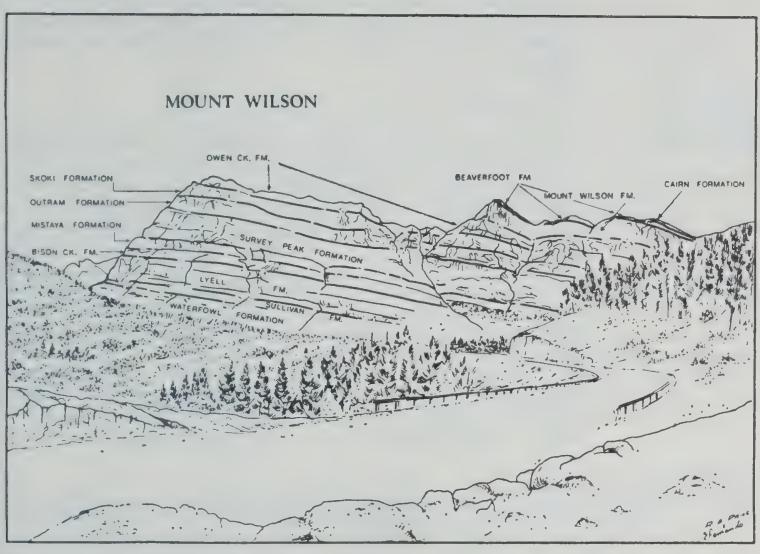

Fig. 8-3. Sketch of Mount Wilson from Highway 93 at Mount Murchison (R. A. Price with E. Fernando).

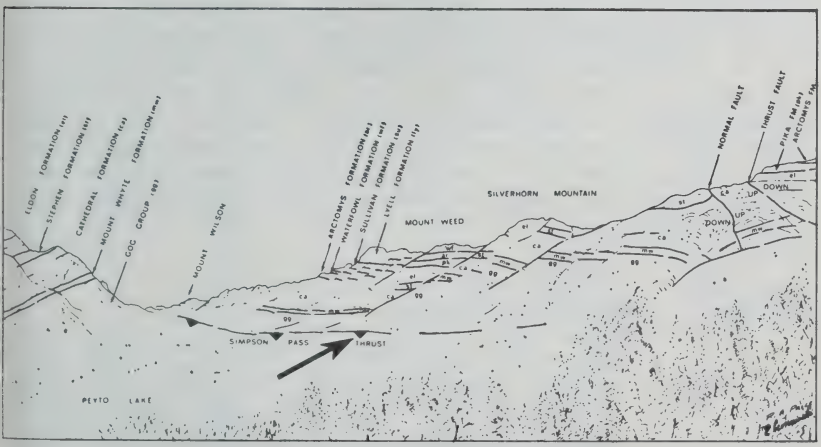

Fig. 8-4. Sketch of the view north along the Simpson Pass thrust from Peyto Lake Viewpoint (R. A. Price with E. Fernando).

The route crosses Bow Pass (6,787 feet, 2070 m) and passes Bow Lake. Outcrops there belong to the upper part of the Miette Group (Windermere), which are cut by the Crowfoot dyke of altered diabase.

STOP 8-8 — *Bow Peak*

128.5 miles
(205.6 km)

This is the only locality at which a perceptible angularity of a few degrees is visible at the contact between the Gog and Miette Groups, which according to Aitken (1969) represents a regional unconformity. A one-to two-inch (2.5 to 5 cm) basal pebble conglomerate occurs at the base of the Gog.

The route follows along strike for about 17 miles (27 km), with several outcrops of upper Miette purple and green slates occurring along the road. Gog outcrops occur higher up the mountain slopes and across the valley. This highway joins the Trans-Canada Highway near Lake Louise (Day 1, Stop 1-8). If time permits, additional stops will be made between Field and Revelstoke.

Day 9: The Selkirk Mountains Between Golden and Revelstoke via The Trans-Canada Highway

This part of the excursion is concerned with latest Precambrian and early Paleozoic stratigraphy and stresses the variation in structural style across the eastern part of the core zone of the Eastern Fold Belt. The latter is illustrated, particularly, by the progressive change in structural style of the Lower Cambrian quartzite from flexural-slip folds in the northernmost Purcell anticlinorium in the Dogtooth Mountains, to flexural-flow style near the axis of the Selkirk Fan structure, to curvilinear similar folds just east of the Shuswap Metamorphic complex. This segment also illustrates the presence of several fan structures and the two principal belts of metamorphism in the Eastern Fold Belt (Figs. 2 and 3).

0.0 — *Golden*

15.6 miles
(25 km)

Golden to Donald

The Rocky Mountain Trench along this segment is underlain largely by glacial drift and alluvium overlying weak, thinly interbedded slate and limestone of the Middle Cambrian Canyon Creek and Upper Cambrian McKay Formations. These units are deformed by southwesterly overturned structures characteristic of the Western Ranges sub-province which to the southeast forms the east wall of the Trench.

The Dogtooth Range lies west of the Purcell Thrust and forms the west wall of the Trench. The range is underlain mainly by clastic sedimentary rocks of late Precambrian and Early Cambrian age deformed into several gently southeast-plunging folds and associated thrust faults and transected by three more northerly trending later thrusts of which the Purcell and Dogtooth faults are examples. The Purcell Thrust lies near the base of the far valley wall. The Dogtooth Range represents the northern extension geomorphologically of the Purcell Mountains and structurally of the Purcell anticlinorium.

7.0 miles (11.2 km) — View ahead of the northern Selkirk Mountains underlain by metasediments of the Windermere Horsethief Creek Group in amphibolite facies within this part of the Selkirk metamorphic belt. The topographic grain reflects the predominantly southwest-dipping foliation. To the left is the northeast-dipping slope of Lower Cambrian Hamill quartzite of the Timber Mountain Plate whose sole is the Purcell Thrust.

15.6-41.7 miles (25-66.7 km) — *Donald to Beaver River Bridge* traverses across the northernmost expression of the Purcell anticlinorium

15.6 miles (25 km) — Bridge across the Columbia River at Donald.

15.6-19.1 miles (25-30.6 km) — For the next 3.5 miles (5.6 km) to the first big curve on the highway the roadcuts are in the McKay Group composed of interbedded slate, siltstones, and limestone — much of which is clastic — deformed into complex folds overturned to the southwest. View across to the east wall of the Trench is of mountains underlain mainly by the Middle Cambrian Chancellor Formation of the Porcupine Creek anticlinorium.

19.1-20.5 miles (30.6-32.8 km) — Along the southwest-trending part of the highway past the first big curve the road cuts are in Middle Cambrian Canyon Creek slates displaying a steeply east-dipping cleavage and tight southwest-plunging folds.

20.5 miles (32.8 km) — The Purcell Thrust is inferred to pass under the second big curve where the highway again trends northwest. View to the right of low hills east of the Columbia River that mark the northern-most extension of the Dogtooth Range. The Purcell Thrust passes west of the light-coloured bluffs of Canyon Creek slates.

STOP 9-1 24.0 miles (38.4 km) — *Lower Cambrian Hamill quartzite (Lower Cambrian Gog Group of the Rockies) of the Timber Mountain Plate.*

Pink, purple and white quartzite with crossbedding indicating southwestward flow of currents. Maroon quartzose argillite interbeds have muscovite flakes on bedding planes and are not cut by

cleavage. The quartzite is folded into step-like flexural-slip folds wtih slickensides on the bedding surface about normal to the southeast-plunging fold axes.

24.9 miles (39.8 km) The outcrops here are of the basal part of the Hamill Group gradationally overlying slate and quartzite of the uppermost Windermere Horsethief Creek Group. Limestone and dolomite outcrops south of the highway on Wiseman Creek.

To the left the mountains are composed in their higher parts of rugged crags of Hamill Group quartzite overlain by slate, and in their lower parts, beneath the prominent shoulder, of Horsethief Creek Group (upper slate unit). These mountains lie in the Wiseman Creek Thrust plate. To the left is the dip slope of the Timber Mountain plate beneath the Wiseman Creek Thrust. Straight ahead are the Prairie Hills which comprise a faulted fan-shaped anticlinorium whose west-dipping panel of Hamill and Horsethief Creek rocks lying east of the Dogtooth fault forms the slopes ahead.

24.9-31.5 miles (39.8-50.4 km) For the next 6.5 miles (10.4 km) the outcrops are of silvery slate and phyllite of the Horsethief Creek Group (Windermere, equivalent to Miette Group of the Rockies) with southeast-plunging bedding-cleavage intersections, steep northwesterly plunging kink bands and very steeply plunging elongate strain features.

STOP 9-2
31.5 miles (50.4 km) *On broad curve (pull off to the right of the highway.)*
The outcrops are of the lower Grit unit of the Horsethief Creek Group, with the mineral assemblage — phengite-quartz-chlorite-albite-biotite, that is typically foliated with quartz flattened in the cleavage and commonly with a characteristic blue colour.

32.0 miles (51.2 km) Farther along the highway the west-facing succession is uppermost Lower Grit unit passes westward into the middle Slate Unit of the Horsethief Creek Group. Farther west the slate unit contains thin beds of limestone and dolomite and cleavage dips southwest.

32.8 miles (52.5 km) Sharp bend with outcrops of massive grey dolomite of the Carbonate Unit of the Horsethief Creek Group. A little farther west, the Middle Slate Unit has been overthrust onto the Carbonate Unit along the Dogtooth Fault. West of the fault the cleavage dips northeast.

32.8-41.7 miles (52.5-66.7 km) Proceed south in the Beaver River valley. On the left are intermittent outcrops of closely fractured grit, quartzite, and slate of the Horsethief Creek Group with northeast-dipping cleavage on the west side of the fan-shaped anticlinorium underlying

Prairie Hills. The Beaver River valley is occupied by a normal fault — west-side down. West of the valley are the Selkirk Mountains. The high rugged peaks are composed of Lower Cambrian Hamill quartzite overlying the Horsethief Creek Group which forms the timbered slopes. Detailed studies have revealed two metamorphic "antiforms" outlined by garnet isograds.

41.7-73.0 miles (66.7-116.8 km) The Beaver River Bridge to Albert Canyon section traverses the Selkirk fan-structure. The axis of this structure passes approximately through the Rogers Pass, just west of the eastern Selkirk metamorphic belt. From Glacier west to Albert Canyon all the structures are overturned to the southwest.

41.7 miles (116.8 km) Bridge over Beaver River.

41.-7 46.2 miles (66.7-73.9 km) Continue past outcrops of Horsethief Creek Group grit and slate up to the snowsheds. Cleavage on west side of the Beaver River valley dips southwest.

STOP 9-3 *Just east of the snowsheds*

46.2 miles (73.9 km)

Outcrops north of the highway are of coarse garnet-biotite-muscovite-schist with southwest-dipping foliation and unoriented biotite porphyroblasts.

46.2-50.1 miles (73.9-80.2 km) Continue through the snowsheds to Rogers Pass. Mounds act as avalanche baffles. The magnificent cliffs on Mount Tupper to the north (right) and Mount MacDonald to the south (left) are composed of Lower Cambrian Hamill quartzite outlining the Summit syncline. Horsethief Creek grit and slate form the lower slopes.

STOP 9-4 *At Rogers Pass*

50.1 miles (80.2 km)

View north to the rugged Hermit Range underlain by Hamill quartzite. View south to Asulkan Pass.

50.1-54.6 miles (80.2-87.4 km) Continue south across the pass. Horsethief Creek slate at left has nearly vertical cleavage, along the axis of Selkirk Fan structure, cutting east-dipping beds. The Illecillewaet Glacier, visible ahead, has retreated spectacularly from its farthest advance, far down into the timber, late in the 19th century.

STOP 9-5 *Just west of Loop Brook*

54.6 miles (87.4 km)

Outcrops south of the highway are of cross-bedded Lower Cambrian Hamill quartzite deformed into folds cut by an east-dipping fracture cleavage on the overturned east limb of the Ventego syncline. The syncline is strongly overturned to the west whereas, it will be called from Day 4, near Mount Iconoclast 15 miles (24 km) to the northwest, the syncline is asymmetrical. The core of the syncline passes through the lower part of

Cougar Brook straight ahead and there the tectonically thickened Lower Cambrian Badshot limestone, containing the Nakimu Caves, is overlain by phyllites of the lower Paleozoic Index Formation.

STOP 9-6
57.1 miles (91.4 km)

View to the north (right) is of Badshot limestone and the underlying folded Hamill quartzite which extends westward to form the west limb of the Ventego syncline. These units are also visible on the valley wall to the south. Mount Sir Donald is the pyramid to the east.

57.1-70.8 miles (91.4-113.3 km)

Continue west along the Trans-Canada Highway through lower Paleozoic Index Formation.

60.1 miles (96.2 km)

Outcrops begin of the pyritic black phyllite of the Index Formation with a strong northeast-dipping cleavage. The ridge tops directly above on either side of the valley are composed of Hamill quartzite lying above an east-dipping thrust fault.

Proceed for the next 10.7 miles (17.1 km) through phyllite of the Index Formation. The cleavage dips moderately steeply northeast in the vicinity of the snowshed (mile 63.8, 102.7 km) parallel to the axial planes of folds overturned to the southwest on the east limb of the Illecillewaet synform.

66.5 miles (106.4 km)

West of the snowsheds the cleavage progressively becomes flatter and is nearly horizontal near an altered, ultramafic rock now composed of carbonate, actinolite and talc near Illecillewaet station

67.4 miles (107.8 km)

A landslide is visible in the timber on the south side of the Illecillewaet Valley.

Continue past intermittent outcrops of Index phyllite with generally flat, undulating foliation characteristic of the west or underlimb of the Illecillewaet synform. The ridges bounding the valley to the north and south, however, are underlain by foliated grit and phyllite of the Broadview Formation. The ridge tops must be part of a klippe if the Broadview is indeed a western facies of the Horsethief Creek Group.

STOP 9-7
70.4 miles (112.6 km)

Black phyllite of the Index Formation containing attenuated isoclines parallel with the undulating and folded foliation and deformed quartz lenses and veins.

Proceed west along highway.

70.8 miles (113 km)

Badshot limestone in bush to right (north) followed by intermittent outcrops of quartzite and phyllite of the Hamill Group.

STOP 9-8
71.6 miles (114.6 km)

Below the bridge across the Illecillewaet River, near the mouth of Tangier River

The quartzites of the Hamill Group have undergone similar folding about curved axes. Foliation dips northeastward.

72.1 miles (115.4 km) Proceed westward along the highway — road cuts of quartz mica phyllonite of the Index (?) Formation along the easterly dipping crush zone separating the Shuswap complex from the backfolded or easterly dipping part of the Selkirk Fan structure.

72.7 miles (116.3 km) Illecillewaet River bridge at Albert Canyon.

73.0-94.0 miles (116.8-150.4 km) *Albert Canyon to Revelstoke*

This part of the Trans-Canada Highway passes through the Clachnacudainn salient of the Shuswap Metamorphic complex. The salient comprises one or more sheets of sheared granitoid gneiss, similar to that in the cores of the gneiss domes in the interior of the Shuswap complex, and more or less concordant paragneisses and associated carbonates, calc-silicate rocks, and amphibolite, abundant pegmatite, especially in its western exposures, and foliated "diorite". The gneiss and associated metamorphic rocks appear to form a northwesterly elongated dome containing in its central portion a depression outlined by carbonate-bearing metasediments and amphibolite which is also the site of a discordant quartz monzonite pluton that has yielded a K-Ar date of 110 m.y. It has been speculated that the geniss may represent Hudsonian Basement.

STOP 9-9 73.4 miles (117.4 km) Large outcrops of sheared granodiorite gneiss with a northeasterly dipping foliation. It is cut by numerous deformed pegmatite and aplite dykes but it is not strongly lineated. This gneiss is similar in some respect to the core gneisses of the Shuswap complex.

View northeast shows light coloured beds of the Badshot Formation outlining a southwesterly overfolded anticline with Mohican phyllites and Hamill quartzite seen at Stop 9-8 in the core. The Lower Cambrian reappears from beneath the Illecillewaet synform and is thrust southwestward over sheared Index black phyllite at the margin of the Shuswap complex.

Continue west along the highway through outcrops of paragneiss and granitoid gneiss of Clachnacudainn salient.

78.6 miles (125.8 km) Steeply dipping outcrops of swirled mixed gneiss comprising granitoid gneiss, amphibolite, mobilized leucocratic zones, aplite and pegmatite dykes. The gneisses are cut by moderately east-dipping plastic shears that have caused sigmoidal swirls in the gneiss and have displaced pegmatite dykes.

View southeast of the Albert Peaks where marbles of the Badshot and Mohican Formations and quartzite and schist of the Hamill Group (all of Lower Cambrian) overlie granitoid gneiss. This contact has been traced along the south side of the Illecillewaet Valley, displaced upward on the west side of

steep northeasterly trending faults along East and West Twin Creeks. Marble bands of the Badshot and Mohican Formations are visible near the tops of the ridge to the south as beds dipping southeasterly off the domal structure in the Clachnacudainn salient.

94.0 miles (150.4 km) Revelstoke.

NIGHT AT REVELSTOKE

Day 10: Revelstoke to Mica Dam

This segment of the excursion will show part of the Shuswap Metamorphic complex in the Clachnacudainn salient, the crushed zone along the eastern border of the complex along the Columbia River, and the lithology, structural style, and metamorphic character of the Western Selkirk Mountains (Fig. 2).

0.0 Junction of highway to Mica Dam and Trans-Canada Highway.

0-16.1 miles (0-25.8 km) *Revelstoke to Laforme Creek*
Undulating but generally gently dipping gneisses and schists of the Shuswap Metamorphic complex.

3.5 miles (5.6 km) Gently dipping assemblage of hornblende gneiss, quartzite, calc-silicate gneiss, and quartz-biotite-garnet sillimanite gneiss.

STOP 10-1
6.3 miles (10.1 km) Cliff of gneiss and calc-silicate rocks cut by numerous pegmatite dykes which impose considerable discontinuity on the stratigraphy and structure—typical of conditions in the Fringe zone of the Shuswap complex. The cliffs exhibit some minor flow folds — generally trending about southeasterly (120°) but commonly having curved axes.

12.9 miles (20.6 km) Generally flat-lying gneiss in which feldspar and abundant mafics give it a speckled appearance. The outcrop contains sharply folded bodies of leucocratic granite. Joint surfaces commonly show a bluish green alteration characteristic of retrograde affects along the crushed zones bordering the Shuswap complex on the east.

16.1 miles (25.8 km) *LaForme Creek*

LaForme Creek to Downie Creek
This segment shows outcrops of the crushed zone between the Shuswap complex west of the Columbia River and the westerly directed and backfolded part of the Selkirk Fan structure to the east. Views can be seen of folds on Frenchman's Cap dome.

STOP 10-2
23.7 miles (37.9 km) Outcrops north of Carnes Creek of mylonitized gneisses featured by intensely flattened and drawn out quartz and feldspar. These mylonitic rocks are

also intensely fractured, indicating that the zone between the Shuswap complex and the low-grade rocks to the east has long been one of continued movement in which brittle deformation has outlasted recrystallization.

24.0-35.0 miles (38.4-56.0 km) For the next few miles views across the Columbia River illustrate the style of folds on the east side of Frenchman's Cap dome. The eastern slopes of the Frenchman's cap dome are underlain by mantling gneiss which displays tight folds whose axial planes dip westward but become flatter in the more easterly and lower folds. Folds in the core zone visible in the valley walls of Park and Bourne Creeks, north of Frenchman's Cap, also have axial planes dipping to the west and descend in a series of steps to the east. Thus the enveloping surface of the gneiss dome dips northeastward under the Selkirk Mountain structures.

31.6 miles (50.6 km) Outcrop of black graphitic phyllite. This rock type may belong either to the lower Paleozoic Index Formation or to the possibly Windermere Broadview Formation which underlies much of the upland area east of the Columbia River. There the Broadview Formation dips northeastward under the Index Formation in the westerly directed and backfolded part of the Selkirk Fan structure.

STOP 10-3
39.2 miles (62.7 km) *Downie Creek*

View northeast to the spire of Downie Peak, formed of steeply northeast-dipping and overturned black phyllite of the Index Formation overlain at the peak by the Lower Cambrian Badshot limestone.

Downie Creek to Goldstream River

This segment contains outcrops of metamorphic rocks related to granitic plutons east of the Columbia River and of the lower Paleozoic phyllonites. Folds in Frenchman's Cap, and the Downie Slide will be seen.

STOP 10-4
41.6 miles (66.6 km) View south of Frenchman's Cap showing tight folds overturned to the northeast in the mantling gneisses.

STOP 10-5
43.9 miles (70.2 km) Downie Slide west of the Columbia River, developed in gently east-dipping mantling gneisses of the Frenchman's Cap dome. The breakoff scarp can be seen in the distance below which is a jumbled mass of blocks. The impingement of the slide on the course of the Columbia River has resulted in the formation of Death Rapids — an obstacle on the fur trade route to the Pacific in the early 19th century.

46.7-50.3 miles (74.7-80.5 km) Outcrops of rusty weathering gneiss, schist and dykes of granitoid material.

STOP 10-6
47.8 miles
(76.5 km)

Steeply north-dipping assemblage of gneiss, quartz-mica schist, and poorly foliated granitic dykes. This assemblage is considered to be part of the metamorphic assemblage associated with the western tail of the porhyritic quartz monzonite stock south of the Goldstream River, inasmuch as steep northerly dips are characteristic of this domain in contrast to the gentle northeastward dips of the Shuswap complex.

STOP 10-7
53.1 miles
(85.0 km)

Outcrops of grey siliceous graphitic phyllonite with an anastomosing foliation that dips about 35 degrees to the north-northeast and is cut by more gently dipping shears. Such outcrops lacking stratigraphic markers are typical of much of the pelitic assemblages in the western part of Selkirk Fan structure.

STOP 10-8
54.3 miles
(86.9 km)

Outcrop of northeast-dipping black graphitic phyllite and marble probably belonging to the lower Paleozoic Index Formation.

54.8 miles
(87.7 km)

Outcrop of massive dolomite probably belonging to the Lower Cambrian Badshot Formation.

55.5 miles
(88.8 km)

Goldstream River Bridge.

Goldstream River to Mica Dam — a few outcrops of marble probably belonging to the Badshot Formation as far as Bigmouth Creek. North of Bigmouth Creek there is no outcrop until just south of Mica Creek townsite.

79.1 miles
(126.6 km)

There are outcrops of quartz-mica-kyanite schist probably derived from the Windermere Horsethief Creek Group.

STOP 10-9
85.0 miles
(136.0 km)

Mica Dam

Mica dam is the largest of three dams constructed for the British Columbia Hydro and Power Authority under the Columbia River Treaty between Canada and the United States (Mylrea, 1969).

The dam rises 640 feet (195 m) above the river bed, but the pervious core, which consists of glacial till, extends from bedrock to a total height of about 800 feet (244 m). Except for this core, the base of the dam is founded on river bed deposits up to 150 feet (46 m) thick. Upstream and downstream shells of the dam as planned consist mainly of compacted sand and gravel with a limited thickness of compacted and dumped rock fill for the outer zones. Total volume of soil and rock fill is 42 million cubic yards (32 million m^3). Most of this material has been obtained from the valley floor upstream as far as the Rocky Mountain Trench.

The bedrock consists of Horsethief Creek Group mica schists, composed essentially of biotite and muscovite with variable amounts of garnet, kyan-

ite, and quartz; gneiss composed of more than 70 per cent quartz with variable amounts of mica and plagioclase; and minor marble and pegmatite. Bedding and schistosity dip to 20 to 30 degrees south.

The bedrock provides a good foundation for the dam, allows good tunnelling conditions, and apparently has relatively low permeability. However, extensive investigation for design of excavations, adequate provision for rock supports, and thorough checking on the results of grouting in the dam foundation were required because of the continuity, steepness, and low cohesion of some of the fractures in the rock. Most of these fractures contain mylonite but others contain chlorite and laumontite. Removal of the slumped rock on the dam abutments was required because intense weathering has occurred along fractures in some areas. The mica schist is not suitable for rock fill because it breaks into slabs. The associated gneiss, however, is suitable and is obtained near the dam.

The surficial deposits comprise basal till dated by C_{14} at 22,900±1,500 years B.P., overlain by lake silt and clay, which is covered by sand and gravel containing layers of "till-like material" suggesting glacial re-advances. Volcanic ash identified as Bridge River ash, deposited 2400 years ago, occurs at the damsite. Eight miles (13 km) farther south a lower ash has been correlated by C_{14} determination to be Mount Mazama ash deposited from a centre in Oregon 6,600 years ago. It appears therefore that the lower slopes of the Columbia River valley were free of ice some 6,600 years ago.

Selective processes of glaciation have emphasized structural weaknesses by erosion along them. Mountain slopes with schistosity forming downslope planes of rupture frequently contain steep scarps below which rock slides have developed.

Day 11: Revelstoke to Cache Creek

0.0 *Revelstoke Junction*

From Revelstoke to Sicamous, via the Trans-Canada Highway, through Shuswap Metamorphic complex (Fig. 2).

0.1 miles (0.2 km) Bridge across Columbia River. Mount Begbie, the prominent mountain to the southwest is underlain by quartzite in the mantling gneisses of the Thor-Odin gneiss dome. Mount Copeland, the sharp peak to the northwest, is in mantling gneisses on the south flank of Frenchman's Cap gneiss dome. The Trans-Canada Highway through Eagle Pass, ahead, follows a structural depression between the domes.

STOP 11-1
1.2 miles
(1.9 km)

Side road to right west of the Columbia River. Outcrops of calcareous and pelitic gneisses deformed into tight recumbent folds with westerly trending axes — characteristic for much of the Shuswap complex.

From the Columbia River to Three Valley Lake outcrops are of gently refolded paragneiss, amphibolite, and migmatites of the Mantling Zone.

16.6 miles
(26.6 km)

At Three Valley Lake spectacular outcrops in high cliffs of biotite, biotite hornblende, and biotite garnet amphibolite, augen gneiss, and migmatite with boudins of amphibolite and amphibolite gneiss. The boudins show necking, extension fractures and rotation as much as 90°.

The prominent style of folding is broad warping exposed in the easterly trending joints that form the cliffs. The tight-recumbent folds are not evident because their axes are essentially parallel to the joint surface.

The gneiss complex is cut by basalt and lamprophyre dykes well displayed at the east end of the outcrop. A lamprophyre dyke cutting the core of Frenchman's Cap dome has yielded a K-Ar date of 41 m.y. These dykes are probably related to Eocene volcanism in the Intermontane Zone.

From Three Valley Lake to Sicamous are outcrops of paragneiss, amphibolite and migmatite with abundant interlacing pegmatite of the Fringe zone of the Shuswap Metamorphic complex. Small granitic plutons occur sparingly in the zone a few miles north and south of the highway. Sillimanite disappears about 4 miles (6.4 km) east, and garnet about 2 miles (3 km) east of Sicamous.

STOP 11-3
47.0 miles
(75.2 km)

Sicamous at west end of bridge across the Shuswap River. Outcrops of platy limestone and limy sericite schist and phyllite with metacrysts of biotite and phlogopite — all belonging to the Sicamous Formation (Mount Ida Group). The rocks are typical of the greenschist facies over much of the transitional zone west of Shuswap complex described below.

Sicamous to Chase: The highway traverses a "Transitional Zone" containing poorly exposed, variably deformed rocks ranging in age from Permo-Carboniferous to early Mesozoic and variably metamorphosed to greenschist and lower amphibolite facies. This zone is transitional between the complexly deformed, ductile Shuswap Metamorphic complex of upper amphibolite facies in the heart of the Eastern Core Zone and the mild, brittle deformation of the essentially unmetamorphosed rocks of the Intermontane Zone.

The strata in this "Transitional Zone", belonging to the Mount Ida Group, were formerly regarded

as Precambrian (Jones, 1959) but regional considerations derived from completion of reconnaissance mapping suggest that the rocks range in age from Permo-Carboniferous to early Mesozoic. The low-grade pegmatite-bearing pelitic and limy rocks — including the Sicamous Formation — traversed by the highway from Sicamous to just west of Sorrento on Shuswap Lake, are possibly of Late Triassic age lying in a northeast-trending synclinorium. The greenstone and chlorite schist west of Sorrento is probably correlative with the Fennel greenstone of late Paleozoic age. This unit in turn is underlain by schists and gneiss of amphibolite facies, possibly representing metamorphosed Cambrian and Windermere strata, occurring in the core of the anticlinorium and intruded by granitic plutons. A post-tectonic body of leucoquartz monzonite at the west end of Salmon Arm yielded a biotite K-Ar date of 127 m.y.

Some of the higher hills, e.g. Mount Ida and Black Mountain are capped by Tertiary volcanics.

STOP 11-4
51.0 miles
(81.6 km)

Shuswap Lake Scenic Lookout Stop.

STOP 11-5
98.9 miles
(158.2 km)

South side of highway on hill east of Chase. Outcrops of quartz mica schist and gneiss, and micaceous quartzite containing foliated aplite veins. These strata are thought to be metamorphosed Cambrian and Windermere sediments. They show an axial plane foliation outlined by micas and well developed lineation plunging at about 25 degrees to the northeast.

These strata, from which K-Ar dates of 135 and 140 m.y. were obtained 2 miles (3.2 km) to the east, are cut by dykes of fine-grained muscovite granite which are intruded by dykes of felsite and grey and green feldspar poryhyry presumably of Tertiary age.

Chase to Kamloops: The highway follows the valley of the North Thompson River. For the first 10 miles (16 km) it traverses the western flank of an anticlinorium intruded by a granitic pluton. The strata exposed on the surrounding hills are Upper Triassic pelites succeeded by relatively fresh porhyritic augite andesite typical of Upper Triassic and/or Lower Jurassic volcanics 40 miles (64 km) to the northwest. These volcanics are separated by a northwest-trending fault from slightly foliated massive greenstones typical of the Permo-Carboniferous volcanics in the Canadian Cordillera. A few miles northwest of the highway the greenstone appears to underlie fossiliferous Permo-Carboniferous limestone. These rocks are overlain unconformably by Tertiary volcanics.

For about 5 miles (8 km) on either side of the village of Monte Creek the valley wall of the

Thompson River is underlain by presumably Upper Triassic, generally massive andesite and subordinate basalts. Basal conglomerate, 150 feet (46 m) thick on the north valley-wall overlies the Permo-Carboniferous with erosional unconformity. These massive Mesozoic volcanics mark the easternmost part of the Intermontane Zone (Figs. 1 and 4).

The rest of the outcrop north and south of the valley is of Permo-Carboniferous greenstone, argillite, phyllite, and limestone. The last is quarried by La Forge Cement north of the Thompson River. Limestones in this region have yielded fusilinids and shelly fauna. Fusilinids indicate the presence of the Morrowan (Early Pennsylvanian), Wolfcampian-Leonardian (Early Permian), and Guadalupian (Late Permian) stages in limestone a few miles north of the highway. The structure of these rocks has not been studied in detail.

Prominent features of the South Thompson River Valley are the silt cliffs that dominate the lower landscape. These silts were deposited in a glacial lake referred to as Lake Thompson (Mathews, 1944) trapped between ice dams in the Shuswap Lake region and a westward retreating ice tongue in the Thompson River valley (Fulton, 1967).

(Kamloops — stoplight at base of big hill — mile 128.6, km 205.8).

Kamloops to Savona: The geology visible from the highway west of Kamloops is dominated by the poorly bedded, rounded outcrops of Upper Triassic Nicola Group beds intruded by monzonite and quartz monzonite of the Iron Mask batholith which contains numerous copper showings. These two units are overlain by early Tertiary basalt, andesite, and rhyolite, commonly with coarse continental clastics at the base.

For the first 15 miles (24 km) west of Kamloops the highway is mainly crossing Tertiary volcanics. South of the highway, 7.3 miles (1.7 km) west of Kamloops are workings and dumps of the Iron Mask Mine which shipped 182,000 tons of 1.47 per cent copper between 1908 and 1928. Chalcopyrite occurs there in lode, stockworks, and in low grade disseminations in the Iron Mask batholith.

Several depressions in the terrain underlain by the Tertiary volcanics contain small lakes and ponds containing deposits mainly of Na_2SO_4 with varying amounts of Na_2CO_3, $MgSO_4$, $MgCO_3$, $CaSO_4$, and NaCl.

After passing outcrops of monzonite containing copper showings at mile 153.8 (km 246.1) the highway traverses Nicola Group rocks all the way to Savona.

STOP 11-6
162.6 miles
(260.2 km)

Savona Lookout.

View north of Nicola volcanics overlain by northeast-dipping coarse clastics of uncertain age. The conglomerates contain clasts mainly of chert and quartzite of the Permo-Carboniferous Cache Creek Group but also of greenstone, andesite, limestone and granitic rocks. These sediments may be as old as Lower Jurassic. The sediments are succeeded by purplish basic tuffs of late Mesozoic or early Tertiary age that form the colourful "Painted Bluffs". They are intruded by augite porphyry and granite. Mercury showings occur in purple tuffs and older rocks. Small production of mercury has come from cinnabar in dolomite veins in ankeritized volcanic breccia.

South of the highway are outcrops of andesite tuff and breccia and volcanogenic clastics cut by southwesterly dipping faults. The outcrops exhibit crossbedding, graded bedding, slump structure and soft-rock deformation. Some of the breccia may be consolidated volcanic mud flows. Argillaceous beds nearby contain *Monotis* and at the west end of the outcrop there are a few *Spongiomorphs,* coral-like animals. The rocky knolls below the highway comprise well-developed pillow lava. (Savona Bridge — mile 167.6, km 268.2).

Savona to Cache Creek: The lower slopes of the Thompson River valley are underlain by rounded, glacially moulded outcrops of andesite and basalt of the Nicola Group intruded by the northern part of the Late Triassic to Early Jurassic Guichon batholith. These units are overlain unconformably by the Middle Eocene volcanics of the Kamloops Group which are overlain by the Miocene Plateau basalt lavas, both of which form steep cliffs and rugged outcrops, in marked contrast to those of the Nicola Group.

The Nicola Group has been studied in detail only in one area 50 miles (80 km) to the south. There it consists of a total of more than 22,000 feet (6,710 m) of Upper Karnian and (?) Lower Norian feldspathic volcanics grading upward into sediments overlain by Norian augite-bearing volcanics that grade upward into sediments (Schau, 1970). The Nicola Group is poorly bedded, making interpretation of its structure difficult. In general it is fractured and faulted and deformed into broad folds.

The Guichon batholith, which varies more or less concentrically from quartz diorite on the outside to quartz monzonite in the core, intrudes Norian (Upper Triassic) strata and contributed granitic detritus to Sinemurian (?) (Lower Jurassic) strata (Frebold and Tipper, 1969). K-Ar dates on various phases of the batholith are all about 200 m.y.

No range of time between the intrusion of the various phases is discernible within the range of experimental error (Northcote *et al*, 1969). Porphyry copper deposits in the Guichon batholith have, over the last 10 years, yielded about $275,000,000 worth of copper (to 1969).

The Kamloops volcanics — basalt, andesite, rhyolite, and trachyte — have yielded K-Ar dates of 49 and 45 m.y. (Middle Eocene, Mathews, 1963). Similar dates have been obtained from the Princeton basin, 100 miles (160 km) to the south, where volcanics are associated with sediments containing mammal teeth and fossil plants of Middle Eocene age (Rouse and Mathews, 1961).

The Plateau lavas, which occur almost entirely north of the highway and are extensively developed in central British Columbia, have yielded several K-Ar dates of 10 to 13 m.y. (Mathews, 1963). They overlie unconformably the Eocene volcanic rocks and thus demonstrate a widespread period of erosion in the mid-Tertiary.

STOP 11-7
180.1 miles
(288.2 km)

Cliffs north of road are of very coarse conglomerate, breccia, welded tuff and basalt flows. This poorly consolidated sequence contrasts with the massive and shattered nature of the Nicola volcanics.

The remaining distance to Cache Creek is mainly over moderately fossiliferous Lower and Middle Jurassic clastic sediments that include conglomerates. The basal conglomerate contains abundant granite debris derived from the Guichon batholith.

STOP 11-8
187.9 miles
(300.6 km)

A road cut west of the village of Cache Creek exposes outcrops of a mélange in the Permo-Carboniferous Cache Creek Group. The south end of the outcrop displays ribbon chert with folds overturned to the northeast and plunging to the southeast. Farther north along the outcrop the mélange consists of nodules and blocks of chert in a groundmass of more highly deformed pyritic black argillite and slate displaying irregular, locally recumbent folds plunging west. Sulphur leached from the pyritic, pelitic groundmass has been reprecipitated as small crystals of gypsum.

North and south of this mélange outcrop the Cache Creek Group contains numerous small bodies of serpentine that have been explored for chromite.

NIGHT AT CACHE CREEK

DAY 12: CACHE CREEK TO VANCOUVER (FIG. 1)

Cache Creek to Spences Bridge. For the first 27 miles (43.2 km), nearly as far as Spences Bridge, the Trans Canada Highway follows the west side

of the Thompson River valley underlain by the Permo-Carboniferous Cache Creek Group. The clastic-volcanic facies, probably also that of the mélange, are poorly exposed in the open rolling sagebrush country adjacent to and mainly east of the highway. Reddish and rusty pyritic gossans are clearly visible from the highway. None contain economic minerals. The massive limestone facies of the Cache Creek Group can be seen on the bluffs of the Cornwall Hills, west of the highway about 10 miles (16 km) from Cache Creek.

The rounded hills east of the highway, between it and the Thompson River, are underlain mainly by Lower and Middle Jurassic sediments. Here and there the hills are capped by Tertiary volcanics. An outlier of columnar basalt dips gently westward on the east wall of the Bonaparte River valley about 2 miles (3 km) southeast of Cache Creek. It is underlain by a thin sequence of sandstones, shales, and coal that has yielded a small flora suggesting a Tertiary age not younger than Miocene, underlain by clays and gravels that form the bank of the river. Duffel and McTaggart (1962) suggest that the outlier and underlying sediments ". . . slid to its present position after breaking away from the edge of a formerly more widespread deposit, since eroded away".

STOP 12-1
19.0 miles (30.4 km)

View east across the Thompson River valley to moderately northwest-dipping predominantly volcanic strata of the Upper Triassic Nicola Group, intruded by the Late Triassic to Early Jurassic Guichon batholith underlying the higher parts of the hills to southeast. Boulders of Guichon batholith rocks are found in the Lower and Middle Jurassic strata occuping the valley upstream in the middle distance. Looking west across the highway are outcrops of porphyritic greenstones of the Cache Creek Group containing phenocrysts of plagioclase and rarely of quartz.

27.6 miles (44.2 km)

At mile 27.6 (km 44.2) the highway enters the Spences Bridge Group that has yielded late Lower Cretaceous fossil plants at two or three localities. The group is mainly volcanic comprising a gently folded succession about 5,000 feet (1520 m) in thickness that underlies entirely the mountains around the town of Spences Bridge. It includes varicoloured pyroclastics and flows of andesite, dacite, basalt and rhyolite commonly porphyritic with phenocrysts of plagioclase. The group overlies unconformably Permo-Carboniferous, and Upper Triassic strata and granitic rocks of the Guichon and Mount Lytton batholiths.

(Town of Spences Bridge at the junction of the Thompson and Nicola Rivers — mile 31.0, km 49.6).

Spences Bridge to Lytton: The valley of the Thompson River becomes narrower and deeper south of

Spences Bridge where it is incised into the late Lower Cretaceous volcanics and the granitic and metamorphic rocks underlying them. Unconsolidated deposits are plastered onto the lower parts of the steep valley and, where composed of silts and when saturated with water, have been subject periodically to landslides. One such slide killed several residents just west of Spences Bridge and another has created more or less continuous instability of the highway near Drynoch (mile 36.1).

STOP 12-2
35.4 miles
(56.6 km)

Maroon and dark green amygdaloidal epidotized basalt flows are exposed here. The flows are gently folded, dip mainly northeast, and are cut by moderately northeast-dipping shears. These volcanics have been mapped with the Albian Kingsvale Group but along the Thompson River valley their assignment to the Kingsvale is uncertain and they may well be part of the Spences Bridge Group. Farther southeast, however, west of the Nicola River, where the Kingsvale volcanics are probably more than 3,000 feet (915 m) in thickness, they can be readily distinguished from the underlying Spences Bridge Group by an intervening clastic sedimentary unit that contains stems and leaves of fossil plants of Albian age.

Continue along the Thompson River through the Lower Cretaceous volcanic sequence, then pass into gneisses and schists (mile 48.4, km 77.4) with lenses and patches of amphibolite well displayed on the north valley wall of the Thompson River. Their age and correlation is not known.

50.4 to
55.2 miles
(80.6 to 88.3 km)

The highway traverses the grandodiorite and quartz diorite of the Mount Lytton batholith.

STOP 12-3
51.7 miles
(82.7 km)

Altered, foliated hornblende quartz diorite of the Mount Lytton batholith, intruded by pink aplite and pegmatite dykes. The batholith was emplaced some time between the Late Triassic and the late Early Cretaceous. It intrudes Upper Triassic strata in areas to the southeast and contributed debris to the unconformably overlying Aptian rocks. A K-Ar age of 143 m.y. (latest Jurassic) was obtained from biotite about 50 miles (80 km) southeast of this stop. The batholith is faulted against Lower Cretaceous sediments in the Fraser Valley zone to the west.

Lytton, in the Fraser Canyon — mile 55.2, km 88.3 — marks the eastern edge of the Cascade Fold Belt.

Lytton to Hope: The highway follows the deeply incised Fraser River Canyon throughout this segment of the route. The canyon lies essentially within two grabens. The northern graben extends south-southeastward from Lillooet, 35 miles (56 km) upstream from Lytton, to Boston Bar (mile 81.2, km 129.9). The southern half of the northern graben lies between the Pasayten Fault on the east and the Hoza-

meen Fault and possibly a northerly splay from it on the west. The northern half of the northern graben is much broader and is bounded on the west by splays that curve more northwesterly. The faults isolate marine and non-marine clastic sediments of mainly Lower Cretaceous age but including also Lower and Middle Jurassic strata and a sliver of continental Eocene. These strata lie between the Mount Lytton batholith and unconformably overlying Lower Cretaceous volcanics on the east, and granitic plutons and metamorphic terrain of the Coast Mountains on the west.

The Mesozoic clastic sediments were derived largely from the plutonic and volcanic terrain of the Intermontane Zone to the east and were deposited in the Tyaughton trough developed along the eastern margin of the Western Fold Belt. From evidence along the fold belt, 100 miles (160 km) or so each side of the Fraser River, the Mesozoic rocks were folded and thrust northeastwards in early Late Cretaceous time. There is some suggestion that right-hand wrench movement took place along the principal faults in Late Cretaceous time, followed by further normal movements in the early Tertiary, prior to the emplacement of the discordant, latest Eocene to Oligocene, granitic plutons in the eastern part of the Cascade Fold Belt (Fig. 4).

The southern graben extends southward from Boston Bar past Hope at least to the International Boundary. It leaves the belt of Tyaughton trough Mesozoic sediments and gradually cuts across the Axial zone to the Cascade Mountains segment of the Western Fold Belt. The Axial zone is marked by the greatest concentration of granitic plutons and by gneisses developed from upper Paleozoic rocks of the Hozameen Group, typical of the pelite-chert-greenstone-serpentine facies of the Permo-Carboniferous of the Canadian Cordillera.

The southern graben contains non-marine Eocene clastics and the mylonitized Custer gneiss. It is bounded on the east by the Yale Fault — a topographic lineament marked by a zone of extensive mylonitization. This zone is characterized by minor folds indicating that the west side of the fault has moved down. The Yale Fault probably continues south of the International Boundary where it is expressed as the Straight Creek Fault which shows the same sense of vertical movement. The western boundary of the graben is marked by the Hope Fault — another profound topographic lineament — along which steeply dipping and folded Eocene rocks are brought against latest Cretaceous and older granodiorite and quartz diorite plutons and also presumably upper Paleozoic metamorphic rocks. The graben is intruded by latest Eocene to Miocene granodiorite and quartz diorite plutons.

From Lytton (mile 55.2, km 88.3) to mile 75.4 (km 120.6) the highway intersects outcrops of the Lower Cretaceous Jackass Mountain Group composed of commonly graded-bedded sandstones, shale and conglomerate. In Manning Park area, 80 miles (129 km) to the southeast, the group ranges in age from Late Hauterivian to Early Albian. The sandstones in the lower part of the section are composed mainly of volcanic clasts. Those higher in the section are arkosic, containing considerable granitic and metamorphic debris.

STOP 12-4
64.8 miles (103.7 km)

Below Jackass Mountain in conglomerate of the Jackass Mountain Group. It is composed of well-rounded clasts of granitic rocks, chert, argillite, and volcanic rocks. The beds dip gently northeast but the clasts display a westerly dipping imbrication. This conglomerate has been dated as Lower Albian in the Manning Park area.

From mile 78.1 to mile 81.2 (km 125 to 129.9) the highway passes through phyllites of the Lower and Middle Jurassic Ladner Group. (Boston Bar — mile 81.2, km 129.9).

84.7 miles (km 135.5)

Road cut of serpentine just west of the Hozameen Fault that forms part of the Coquihalla serpentine belt that lies entirely within the upper Paleozoic Hozameen Group exposed in a road cut at mile 86.6 (km 138.6).

From mile 84.7 to mile 134.1 (km 135.5 to 214.7) the highway traverses the Axial zone of the Cascade segment of the Western Fold Belt. Outcrops of the Custer gneiss, of concordant foliated plutons of latest Cretaceous and older granodiorite and quartz diorite such as the Spuzzum body and the Yale intrusions, and of Late Eocene to Miocene discordant intrusions such as the Hell's Gate, Scuzzy and Chilliwack plutons are present.

86.7 miles (138.7 km)

China Bar Tunnel driven in Spuzzum tonalite.

STOP 12-5
88.7 miles (141.9 km)

Hell's Gate Fishway Tram

Biotite granodiorite of Hell's Gate Plutons. Note the absence of foliation and sparsity of inclusions. This pluton has yielded a K-Ar date of 35 m.y. The highway passes through the foliated Spuzzum tonalite, composed of 25 per cent hornblende and biotite, and 3 to 15 per cent quartz, which is characteristically gneissoid but which becomes cataclastic east of the Hope Fault. It grades into the Hozameen Group and is cut by the Yale intrusions. It has yielded a K-Ar date of 76 m.y.

95.5 miles (152.8 km)

Alexandra Bridge.

Mile 100.6 to 102.2 (km 161 to 163.5)

Outcrops of schist, gneiss and marble formed from Hozameen strata during the regional metamorphism accompanying the emplacement of the Spuzzum tonalite.

102.4 to 107.5 miles (163.7 to 172 km)

Road cuts of sheared plutons of the Yale intrusions which consist mainly of sills of pale grey to white-sheared granodiorite and tonalite, commonly with feldspar augen that enclose angular inclusions of relatively unfoliated Spuzzum tonalite and Custer gneiss.

Just south of the Yale road tunnel (mile 107.5, km 172) are the most northerly exposures of the Custer gneiss, an assemblage of migmatite, gneiss, and schist probably formed during late Paleozoic or early Mesozoic time.

107.6 miles (172.2km)

Yale — Head of navigation on the Fraser River.

108.1 to 121.0 miles (173 to 193.6 km)

The highway passes through several outcrops of whitish, shattered mylonitized Custer gneiss. Two miles (3 km) south of Yale, on the east side of the Fraser River is Hill's Bar, which is estimated to have yielded 2 million dollars in placer gold in 1858.

Mile 114.5 (183.2 km)

Choate. Four miles (6.4 km) east of the highway is the Pacific Nickel Mine. The ore deposits are disseminated and massive pyrrhotite, pentlandite, and chalcopyrite in a stock-like mass of pyroxenite and peridotite that intrudes a diorite phase of a quartz diorite pluton.

122.6 miles (196.2 km)

Hope bridge across the Fraser River.

STOP 12-6
122.7 miles (196.3 km)

Outcrop of Eocene conglomerate containing boulders of leucrocratic granitic rocks, greenstone, greywacke, chert, quartzite, and chlorite schist. The conglomerate lies unconformably on the Custer gneiss, dips steeply west, and to the west is brought by the Hope Fault against late Mesozoic quartz diorite. Sandstone beds associated with the conglomerate have yielded Eocene plants.

Hope to Chilliwack (Lickman Road)

From Hope the highway continues to follow the Fraser River valley which here turns abruptly westward and in so doing provides a section across the western part of the Axial zone, which is occupied mainly by Late Cretaceous and Miocene granitic plutons.

As the valley leaves the Axial zone, roughly near Laidlaw (mile 133.0, km 212.8) it trends southwestward across the western zone of the Cascade Segment of the Western Fold Belt.

The strata of the Western Zone range in age from Late Devonian to Lower Cretaceous and include the pre-Devonian crystalline basement of Vedder Mountain in tectonic slices near the eastern limit of the Western Zone.

Sediments which contain Upper Devonian fossils just south of the International Boundary, extend

into Canada southeast of the pre-Devonian crystalline rocks of Vedder Mountain. The upper Paleozoic succession comprises fine-grained clastics succeeded by Lower Pennsylvanian limestone, which is overlain discomformably by more clastics and mixed pyroclastics, that are succeeded by Lower Permian limestone in an uppermost unit of greenstone and cherts. It probably represents deposition in a volcanic island arc environment.

Mesozoic rocks disconformably overlie the Paleozoic. They comprise a succession of flysch-like pelites, siltstones, and sandstones ranging in age from Late Triassic to Early Cretaceous. The sedimentary character of the sequence is in marked contrast to the volcanic assemblages in the Intermontane Zone and probably represents deposition in a trough lying west of the Nicola Group volcanic arc. North of the Fraser River, however, intermediate to felsic volcanics are important in the Middle Jurassic.

Lower Cretaceous strata are rich in quartzofeldspathic and granitic debris. Jeletzky (1970, p. 222) has shown that this debris could not have come from plutonic terrains in the Coast Mountains to the north.

South of the river the upper Paleozoic and lower and mid-Mesozoic strata are stacked into three gently dipping thrust sheets transported apparently northwestward over an autochthonous and parautochthonous mass containing pre-Devonian basement. All of these structural units are featured by northeasterly trending recumbent folds. South of the International Boundary they swing southward around a westward convex salient. North of the Fraser River the folds and traces of the thrust faults swing northerly and then northwesterly parallel to the valley of Harrison Lake.

These northeasterly trending folds and associated thrust sheets involve strata, south of the International Boundary, as young as Lower Cretaceous (Misch, 1966) but do not deform latest Cretaceous and earliest Tertiary sediments. Accordingly the principal deformation in the western zone took place in Middle to Late Cretaceous time. The thrust sheets are warped into broad folds, cut by northerly trending reverse faults with west side down, and by associated minor structures such as conjugate and chevron folds, kink-bands and crenulation cleavage. All these are tentatively correlated with well-documented Early Eocene deformation along the south side of the Bellingham Basin near the western end of Vedder Mountain. From mile 123.5 to 127.0 (km 197.6 to 203.2) the lower slopes of Hope Mountain on the left are underlain by Custer gneiss which is overlain unconformably by Eocene conglomerate.

From near Silverhope Creek (mile 127.0, km 203.2) to just past Laidlaw (mile 133.0, km 212.8) the road cuts are in Late Cretaceous quartz diorite from which K-Ar dates of 102 and 80 m.y. have been obtained. From mile 133.0 (km 212.8) to near Cheam (mile 140.0, km 224.0) road cuts and adjoining hillsides are underlain by rusty weathering pelitic rocks of late Paleozoic age. The steeply dipping fault zone along which are found lenses of serpentinized peridotite and pyroxenite enters the Fraser Valley at Walleach Creek (mile 134.1, km 214.6). The fault zone roughly marks the boundary between the Axial and Western Zones. Near Popkum (mile 140.0 to 143.8, km 224 to 230.1) outcrops along the road side are of Miocene granodiorite and quartz diorite — the youngest intrusions in the area dated by K-Ar at 16, 18, and 23 m.y.

From mile 145.9 (km 233.4) at Mount Cheam the highway gradually diverges from the mountain front to the southeast and traverses the flood plain of the lower Fraser Valley. Recumbently folded strata can be seen on the cliffs of Mount Cheam. Limestone quarried near Popkum has yielded Lower Permian fusilinids.

STOP 12-7
156.6 miles
(250.6 km)

At Lickman Road south of the Trans Canada Highway — View of the Cascade Mountains in the distance. To the left, looking east, is Mount Cheam and the timbered ridges of the Chilliwack Valley which are underlain by the gently warped and relatively flat thrust sheets containing strata ranging in age from Lower Pennsylvanian to Upper Jurassic.

The sharp peaks in the distance — the spire of Mount Slesse on the left and Tomyhoi Peak on the right are in the complexly imbricated zone along the eastern margin of the Western Zone which contains numerous slivers and lenses of quartz diorite and amphibolite that are considered to be tectonically emplaced masses of pre-Devonian basement.

Farther to the right is Mount McGuire with recumbently folded light grey Lower Permian limestone of the middle thrust sheet on its summit. Still farther to the right is Church Mountain. There tightly folded Lower Permian rocks on top are part of the parautochthonous mass beneath the lowest thrust sheet.

To the south and southwest is Vedder Mountain, containing pre-Devonian crystalline rocks.

Chilliwack (Lickman Road) to Vancouver

The highway continues westward along the Fraser delta plain. To the right, at mile 160.0 (km 256.0), is the low hill of Chilliwack Mountain underlain by Middle Jurassic volcanics.

The highway passes Sumas Mountain at mile 168.0 (km 268.8). The northeast end of the mountain is underlain by Middle Jurassic and the southwestern end by granitic rocks which are overlain unconformably by nearly flat-lying Middle Eocene clastic sediments, including clay mined for use in tile and brick. View to left in distance is of Mount Baker, in the State of Washington, which is a Pleistocene and Recent volcanic cone, part of the north-trending Cascade chain of volcanoes.

208.5 miles (333.6 km) Port Mann Bridge.

North of the Fraser River, Burnaby Mountain is composed of Middle Eocene sandstone, shale, and conglomerate dipping 15 degrees south. The nonmarine Tertiary sediments underlying much of the city of Vancouver and exposed in low hills within and around the lower Fraser Valley were deposited in the Bellingham Basin.

(End of Highway 401 - mile 218.6, km 351.9).

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We have depended upon many sources of material in writing the guidebook, and insofar as possible such sources have been referenced in the text.

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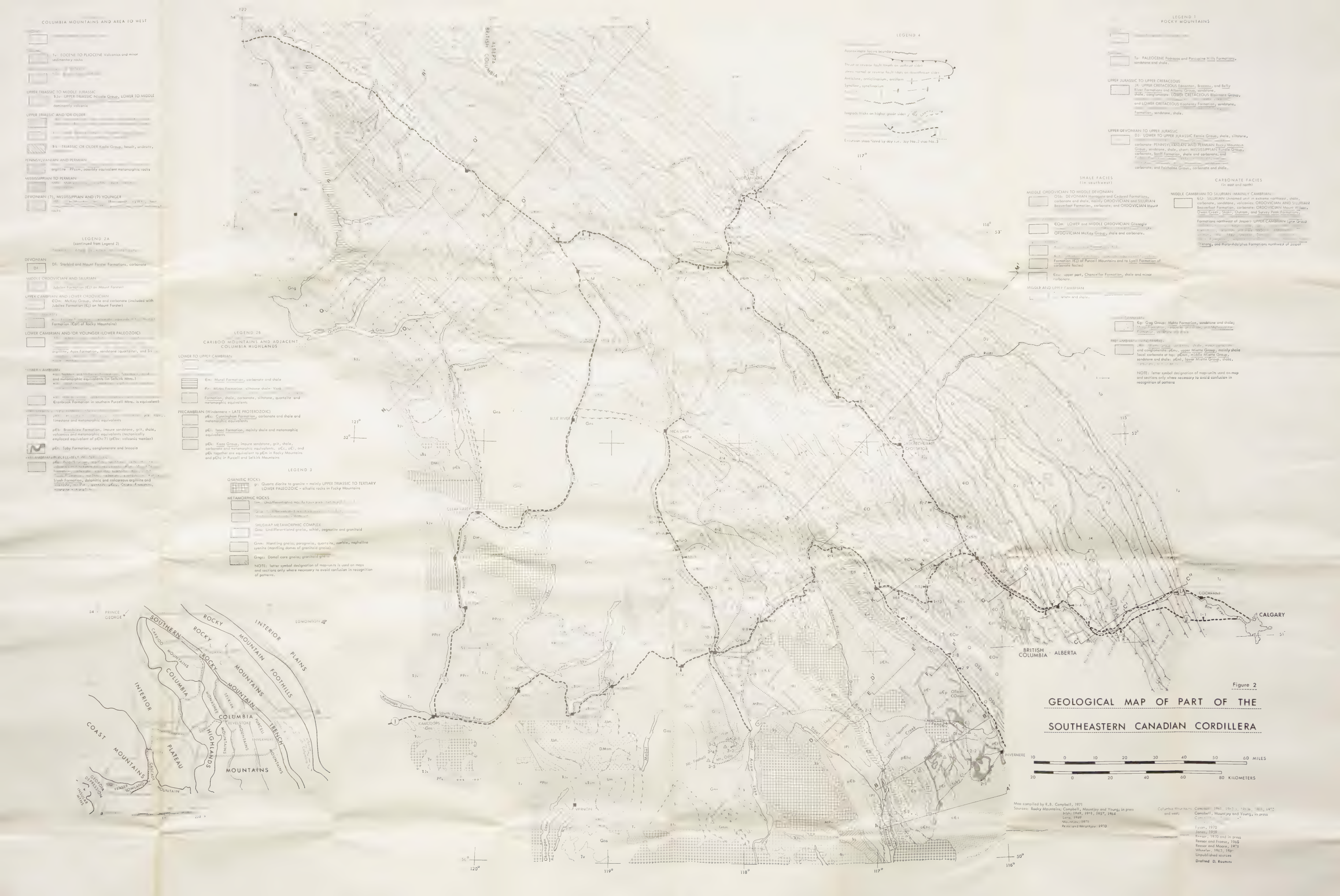
GEOLOGY


COLUMBIA MOUNTAINS AND AREA TO WEST
Tv: EOCENE TO PLIOCENE Volcanics and minor sedimentary rocks
UPPER TRIASSIC TO MIDDLE JURASSIC
TJv: UPPER TRIASSIC Nicola Group, LOWER TO MIDDLE JURASSIC dominantly volcanic
UPPER TRIASSIC AND/OR OLDER
TK: TRIASSIC OR OLDER Kaslo Group, basalt, andesite,
PENNSYLVANIAN AND PERMIAN
argillite PPcm, possibly equivalent metamorphic rocks
MISSISSIPPIAN TO PERMIAN
DEVONIAN (?), MISSISSIPPIAN AND (?) YOUNGER
rocks
LEGEND 2A
(continued from Legend 2)
DEVONIAN
Dl: Starbird and Mount Forster Formations, carbonate
MIDDLE ORDOVICIAN AND SILURIAN
Jubilee Formation (€j on Mount Forster)
UPPER CAMBRIAN AND LOWER ORDOVICIAN
€Om: McKay Group, shale and carbonate (included with Jubilee Formation (€j on Mount Forster)
Formation (€at of Rocky Mountains)
LOWER CAMBRIAN AND/OR YOUNGER (LOWER PALEOZOIC)
argillite, Ajax Formation, sandstone quartzite, and
PROTEROZOIC
Kaslo, and Metamorphic equivalents (in Selkirk Mtns.)
Kootenay Formation in southern Purcell Mtns. is equivalent)
limestone and metamorphic equivalents
pEb: Broadview Formation, impure sandstone, grit, shale, volcanics and metamorphic equivalents (tectonically emplaced equivalent of pEhc ?) (pEbv: volcanic member)
pEt: Toby Formation, conglomerate and breccia
ARCHEAN OR PROTEROZOIC
Siyah Formation, dolomitic and calcareous argillite and
LEGEND 2B
CARIBOO MOUNTAINS AND ADJACENT COLUMBIA HIGHLANDS
LOWER TO UPPER CAMBRIAN
Em: Munal Formation, carbonate and shale
Formation, shale, carbonate, siltstone, quartzite and metamorphic equivalents
PRECAMBRIAN (Windermere – LATE PROTEROZOIC)
pEc: Cunningham Formation, carbonate and shale and metamorphic equivalents
pEi: Isaac Formation, mainly shale and metamorphic equivalents
pEk: Kaza Group, impure sandstone, grit, shale, carbonate and metamorphic equivalents; aCc, aEi, and pEk together are equivalent to pEm in Rocky Mountains and pChc in Purcell and Selkirk Mountains
LEGEND 3
GRANITIC ROCKS
gr: Quartz diorite to granite – mainly UPPER TRIASSIC TO TERTIARY
LOWER PALEOZOIC – alkalic rocks in Rocky Mountains
METAMORPHIC ROCKS
(m: Undifferentiated rocks, by type, pre-, syn-, post-Monashee Orogeny)
Gneiss, Migmatite, Amphibolite
Undifferentiated – Northeast
SHUSWAP METAMORPHIC COMPLEX
Gns: Undifferentiated gneiss, schist, pegmatite and granitoid
Gnm: Mantling gneiss; paragneiss, quartzite, marble, nepheline syenite (mantling domes of granitoid gneiss)
Gngc: Domal core gneiss; granitoid gneiss
NOTE: letter symbol designation of map-units is used on maps and sections only where necessary to avoid confusion in recognition of patterns.
LEGEND 4
Approximate facies boundary
Thrust or reverse fault (teeth on upthrust side)
Anticline, anticlinorium, antiform
Synclinal, synclinorium
Isograds (ticks on higher grade side)
Excursion stops listed by day i.e., Day No. 2 stop No. 3
LEGEND 1
ROCKY MOUNTAINS
Tp: PALEOCENE Paskapoo and Porcupine Hills Formations, sandstone and shale.
UPPER JURASSIC TO UPPER CRETACEOUS
JK: UPPER CRETACEOUS Edmonton, Brazeau, and Belly River Formations and Alberta Group, sandstone, shale; conglomerate; LOWER CRETACEOUS Blairmore Group, and LOWER CRETACEOUS Kootenay Formation, sandstone, Formation, sandstone, shale.
UPPER DEVONIAN TO UPPER JURASSIC
DJ: LOWER TO UPPER JURASSIC Fernie Group, shale, siltstone, carbonate; PENNSYLVANIAN AND PERMIAN Rocky Mountain Group, sandstone, shale, chert; MISSISSIPPIAN Rundle Group, carbonate, Banff Formation, shale and carbonate; and carbonate; and Fantasque Group, carbonate and shale.
SHALE FACIES
(in southwest)
CARBONATE FACIES
(in east and north)
MIDDLE ORDOVICIAN TO MIDDLE DEVONIAN
OSd: DEVONIAN Hamsgate and Cedared Formations, carbonate and shale, mainly ORDOVICIAN and SILURIAN Beaverfoot Formation, carbonate; and ORDOVICIAN Mount
MIDDLE CAMBRIAN TO SILURIAN (MAINLY CAMBRIAN)
€Zj: SILURIAN Unnamed unit in extreme northeast, shale, carbonate, sandstone, volcanics; ORDOVICIAN AND SILURIAN Beaverfoot Formation, carbonate; ORDOVICIAN Mount Wilson, Owen Creek, Thunder, Outram, and Survey Peak Formations
Formations northwest of Jasper: UPPER CAMBRIAN Lynx Group
Hamsgate and Cedared Formations
€Om: LOWER and MIDDLE ORDOVICIAN Gloucester
ORDOVICIAN McKay Group, shale and carbonate.
Formation (€j) of Purcell Mountains and its Lyell Formation of carbonate facies)
€Ou: upper part, Chancellor Formation, shale and minor carbonate.
MIDDLE AND UPPER CAMBRIAN
Eg: Gog Group: Mahto Formation, sandstone and shale; Naiset Formation, limestone and shale; and Mahoney Formation, dolomite and shale
Eb: Argyle group, dolomitic shale, micaceous sandstone and conglomerate pEmv, upper Miette Group, mainly shale local carbonate at top; pEmm, middle Miette Group, sandstone and shale; pEml, lower Miette Group, shale,
NOTE: letter symbol designation of map-units used on map and sections only where necessary to avoid confusion in recognition of patterns
BRITISH COLUMBIA
ALBERTA
CALGARY
EDMONTON
PRINCE GEORGE
KAMLOOPS
VERNON
PENTICTON
PIVERMERE
OVERLANDER
BLUE RIVER
MICA DAM
SARCHEWAY
CROWSNEST
ROCKY MOUNTAIN TRENCH
INTERIOR PLAINS
ROCKY MOUNTAIN FOOTHILLS
ROCKY MOUNTAINS
SOUTHERN CARIBOO MOUNTAINS
COLUMBIA MOUNTAINS
INTERIOR PLATEAU
COAST MOUNTAINS
INTERIOR LOWLANDS
COLUMBIA HIGHLANDS
SELKIRK MOUNTAINS
PURCELL MOUNTAINS
MONASHEE MOUNTAINS
CASCADE MOUNTAINS
GEORGIA DEPRESSION
FRASER LOWLAND
Figure 2
GEOLOGICAL MAP OF PART OF THE SOUTHEASTERN CANADIAN CORDILLERA
10 0 10 20 30 40 50 60 MILES
20 0 20 40 60 80 KILOMETERS
Map compiled by R.B. Campbell, 1971
Sources: Rocky Mountains; Campbell, Mountjoy and Young, in press
Irish; 1969, 1971, 1957, 1964
Leech, 1960
Wanless, 1970
Reesor and Moore, 1970
Columbia Mountains; Campbell, 1961, 1963, 1967, 1973
and west; Campbell, Mountjoy and Young, in press
Eyson, 1970
James, 1959
Reesor, 1970 and in press
Reesor and Freese, 1968
Reesor and Moore, 1971
Wheeler, 1963, 1965
Unpublished sources
Drafted D. Rusmin

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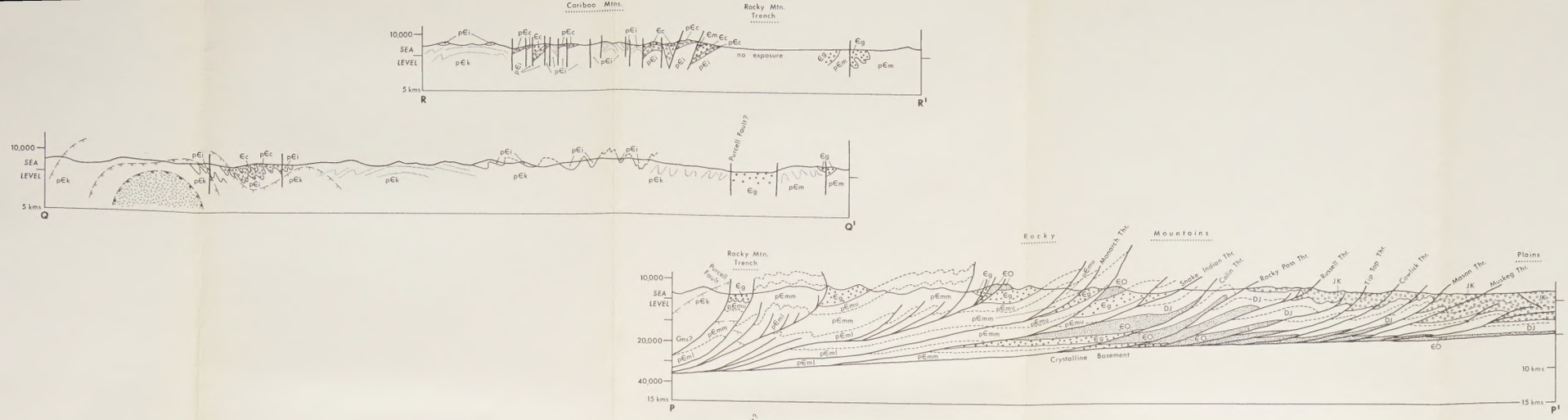
GEOLOGY



Compiled by R.B. Campbell, E.W. Mountjoy, J.E. Reesor and J.O. Wheeler, 1971

Sources: Sections A-A', B-B', E-E', and F-F': from published & unpublished sources including Fyles, 1964 and Fyles and Eastwood, 1962 (J.E.R. and J.O.W.)

Sections C-C'-C'' and G-G': modified from Price, R.A. and Mountjoy, E.W., published by Alta. Soc. Petrol. Geol., June, 1970 (R.B.C.)

Sections H-H' to L-L': modified from compilation by Balkwill, H.R., Cook, D.G., Price, R.A., Simony, P.S., and Wind, G. in unpublished. Geol. Soc. Am. Field Guidebook, May, 1971 (R.B.C.)

Section M-M': modified from Price and Mountjoy, 1970 (R.B.C.)

Sections N-N', O-O', Q-Q' and R-R' (R.B.C.)

Section P-P' (E.W.M.)

5 0 5 10 15 20 MILES

Figure 3

STRUCTURAL CROSS SECTIONS OF PART OF SOUTHEASTERN CANADIAN CORDILLERA

To Accompany geological map – Figure 2
Legend as in Figure 2

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